UMTA-IT-06-0026-79-3

ACT-1

URBAN RAPID RAIL VEHICLE AND SYSTEMS PROGRAM

ENGINEERING TEST OF ACT-1 VEHICLE AT TRANSPORTATION TEST CENTER

Boeing Vertol Company
Surface Transportation Systems
Philadelphia, Pa. 19142

DEPARTMENT OF TRANSPORTATION · UNITED STATES OF AMERICA

DECEMBER 1979
FINAL REPORT

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16. Abstract

This document contains a description of the ACT vehicles as delivered to UMTA, including major changes incorporated during testing at the Transit Test Center (TTC), Pueblo, Colorado, and the rationale for these changes.

The test program is described in detail and results are presented for checkout, adjustment, engineering, and acceptance testing of the ACT vehicles. These vehicle tests include: 1) crash attenuation; 2) performance tests, i.e., acceleration, speed regulation, deceleration, power consumption, thermal duty cycle, slip/spin efficiency, ride quality data, and acoustics data. The instrumentation system description is included in an appendix.

The test program resulted in confirmation of significant achievements in vehicle operating efficiency; technology advances in component design and integration; and of considerations for passenger safety, security, and comfort.

This document, plus Report No. UMTA-IT-06-0026-79-2, ACT-1 Advanced Concept Train Development Program, Phase II: Design, Fabrication, and Functional Test; and Report No. UMTA-IT-06-0026-79-4, Advanced Concept Train (ACT-1) Simulated Demonstration Test Report, together comprise the ACT-1 final report.

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1.0 INTRODUCTION

1.1 BACKGROUND

On June 14, 1971, the Boeing Vertol Company was awarded Contract No. DOT-UT-1007 to perform as systems manager for the Urban Rapid Rail Vehicle and Systems Program. The program was sponsored by the U.S. Department of Transportation's Urban Mass Transportation Administration (UMTA) Office of Research and Development, Rail Technology Division. As systems manager, Boeing Vertol was responsible to UMTA for the overall planning and integration of the program, as well as for all of its technical and management aspects.

The overall objective of the Urban Rapid Rail Program was to enhance the attractiveness of rail rapid transportation to the urban traveler by providing existing and proposed transit systems with service that is as comfortable, reliable, safe, and economical as possible.

The program involved six separate tasks, of which the following three were to involve hardware:

- State-of-the-Art Cars (SOAC) – Design, construction, test, and five-city demonstration of two cars incorporating existing proven advanced technology (Task 3).
- Advanced Concept Train (ACT-1) – Design, construction, test, and five-city demonstration of two cars representative of advanced, operationally tested, improved rapid rail vehicles (Task 4).
- Advanced Subsystem Development Program (ASDP) – Develop alternate subsystems and demonstrate in ACT-1 or SOAC (Task 5).

The remaining three identified tasks were:

- Program management (Task 1).
- Review and monitor progress of BART car demonstration and operation and recommend methods for incorporating improvements established during the BART demonstration in the SOAC and ACT cars, as well as areas for further investigation using the resources of the SOAC, ACT cars, and Pueblo test center (Task 2).
- Planning for the operational demonstration of a rapid rail Advanced Concept Train (Task 6). Implementation of this task was never authorized.

This report records and discusses the goals and achievements of the Advanced Concept Train (ACT-1) during the period of testing at the Transportation Test Center in Pueblo, Colorado, from September 1977 through December 1978, with the exception of the Simulated Revenue Service Testing which is reported separately in Report No. UMTA-IT-06-0026-79-4. The results of the design, fabrication, and functional testing are described in Report No. UMTA-IT-06-0026-79-2.

The ACT-1 program schedule is shown in Figure 1–1. The schedule slide in delivery of the cars to TTC was attributed primarily to redesigns to reduce high vibration and noise and because of motor commutation problems. The slide in the test schedule at TTC was attributed to Energy Storage Unit failures, poor motor commutation, and debugging of the Electronic Control Unit (ECU).

1.2 PROGRAM AND TEST OBJECTIVES

The objectives of the ACT-1 project were to advance the state of the art of rail rapid transit car design and construction and to demonstrate the benefits of advanced technology when applied to rapid transit cars for both existing and future systems. The primary goal was to provide cars that are as comfortable, reliable, safe, and economical as possible. Car operating economics were to be derived and compared, including development and acquisition costs amortized over the useful car miles per year. The ACT-1 vehicles were expected to reduce operating and maintenance costs by up to 32 percent compared to existing vehicles.

The ACT-1 objectives were to be fulfilled by the design and development of two rail rapid transit cars representing the next generation of design, technology, and operating efficiency.

Benefits were to be demonstrated to transit industry personnel, public officials, and the riding public through tests conducted on the UMTA Rail Transit Test Track at the High-Speed Ground Test Center, Pueblo, Colorado, and operating demonstrations on existing rapid rail transit lines in Boston, Chicago, Cleveland, New York, and Philadelphia.

Test objectives were to conduct a comprehensive test program of components, subsystems, and the complete transit car to substantiate the design and performance characteristics, assure operational compatibility with the transit system, and determine that the systems have adequate service lives for revenue service.

Prior to initiating the vehicle system tests, many of the subsystems have undergone detailed laboratory testing to substantiate the design capability. The various tests associated with the ACT-1 component and subsystem test plan are contained in Boeing Vertol Report D174-10039-1.

At the end of the manufacturing phase, the entire vehicle and its subsystems were subjected to a functional test program at the AiResearch Western Avenue Facility (Torrance, California) prior to shipment to Pueblo TTC, in accordance with AiResearch Report 76-12761. The intent was to deliver a fully operative car to Pueblo, with additional functional tests only as required due to vehicle reassembly. Not all tests were successfully completed at the AiResearch Western Avenue Facility and the waivers and deviations were documented separately for each car.

The test plans for the ACT-1 vehicle systems tests at the U.S. Department of Transportation Test Center, Pueblo, Colorado, are documented in Boeing Vertol Report D174-10039-2. This test plan is based upon the ACT-1 requirements contained in the ACT-1 Advanced Concept Train Development Program Design Specification, AiResearch Report No. 72-8771-3, Revision 6,

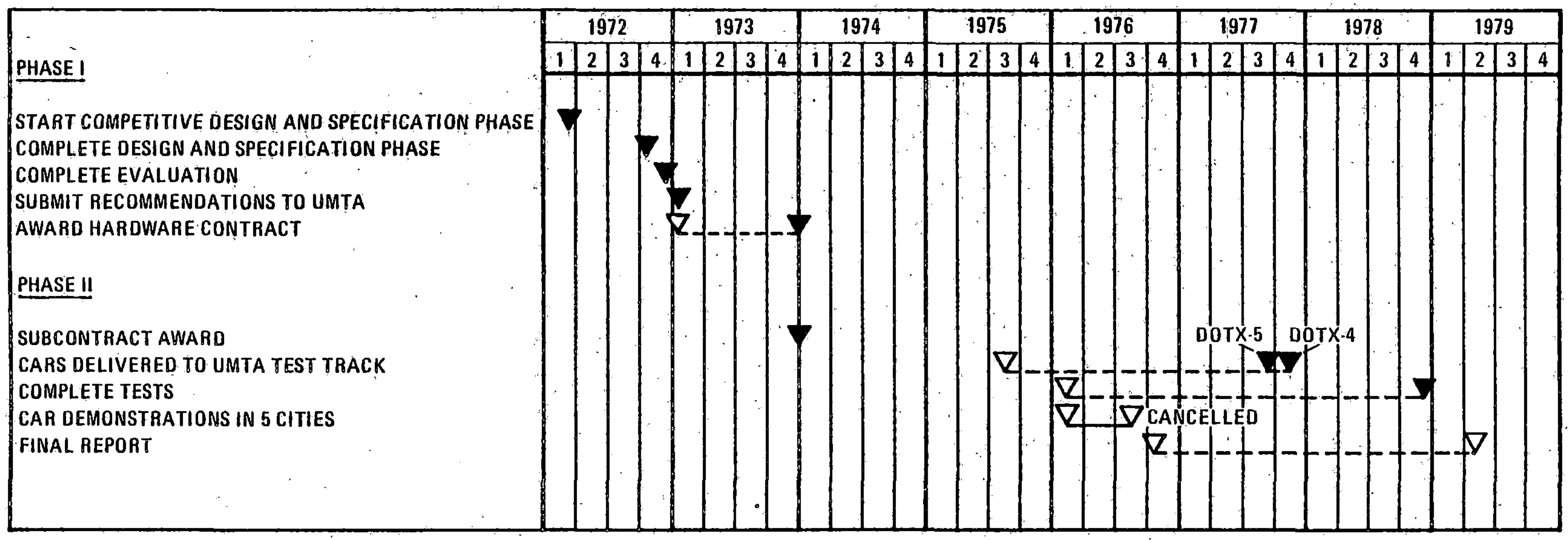


Figure 1–1. ACT-1 Project Schedule

dated June 2, 1975, and in the General Vehicle Test Plan (GVTP) for Urban Rapid Rail Cars, Report No. UMTA-06-0025-14, dated September 1975.

The purpose of the vehicle system testing contained in this plan was threefold:

1. To demonstrate compliance with the ACT-1 Design Specification, Revision 6.
2. To obtain baseline data on the ACT-1 configuration by accomplishing engineering tests similar to those conducted on the State-of-the-Art Car under contract DOT-TSC-580.
3. To obtain service-use data through a simulated revenue service operation of 5,000 train-miles prior to initiating the five-city demonstration tour.

The four test plans associated with the ACT-1 program are:

1. ACT-1 Program Test Plan – Component Testing (Boeing Vertol Report D174-10039-1).
2. ACT-1 Prototype Car – Functional Tests (AiResearch Report 76-12761).
3. ACT-1 Program Test Plan – Vehicle System Testing (Boeing Report D174-10039-2).
4. ACT-1 Test Plan No. 6557, Revision A (Department of Transportation).

The test procedures associated with the testing at TTC are:

1. ACT-1 Vehicle Preliminary Test and Adjustment Test Procedures, Boeing Vertol Report D174-10039-3.
2. ACT-1 Vehicle on Track Acceptance Test Procedure, Boeing Vertol Report D174-10039-5.
3. ACT-1 Vehicle Simulated Revenue Service Test Procedures, Boeing Vertol Report D174-10039-6.

The vehicle delivery documents describing status of the cars when shipped from the AiResearch Western Avenue Facility to the Transportation Test Center in Pueblo are:

1. Prototype Car DOTX-4 Delivery Waivers and Deviations, AiResearch Report 77-14389.
2. Prototype Car DOTX-5 Delivery Waivers and Deviations, AiResearch Report 77-14293, Revision A.

1.3 PROGRAM APPROACH

1.3.1 Concept Definition Phase

A comprehensive ACT-1 project plan was developed in response to the Urban Rapid Rail contract requirements. This plan evolved from the ACT-1 Project Implementation Plan and subsequent discussions with potential subcontractors and UMTA.

A two-phase development program was established. Under Phase I, four contractors were funded to perform a five-month design and proposal effort for the two prototype cars. After the completion of Phase I, Boeing Vertol conducted a comprehensive evaluation and developed a source selection recommendation for Phase II under which prototype cars would be built and tested.

Phase I began on May 15, 1972, with the award of fixed-price contracts for five-month efforts to four contractor teams headed by Garrett-AiResearch, General Electric, Rohr Industries, and Vought Aeronautics. Members of the teams were as follows:

Garrett-AiResearch	General Electric	Rohr Industries	Vought Aeronautics
Peter Muller Monk Assoc	Lowey-Snaith	Sundberg-Ferrar	Teague
Pullman	Grumman	Bechtel	GM-Delco
Gibbs & Hill		Cornell Labs	TRW
Battelle			

Each of the four ACT-1, Phase I, contractors submitted a study result, a preliminary design and design substantiation, a development specification for the prototypes, and a firm proposal to manufacture and test prototypes. These submittals were received by Boeing Vertol on October 16, 1972.

The evaluation of the submittals resulted in a recommendation to UMTA on January 24, 1973, to award two contracts for the Phase II fabrication of prototype hardware. UMTA concurred in this recommendation.

A Transportation System Acquisition Review Committee (TSARC) was convened by DoT to consider UMTA's request to expand the ACT program from one to two awards for prototype hardware. The recommendation of TSARC was to award one contract for the prototype hardware and to significantly expand the subsystems program, then designated ACT-2. The contract for Phase II of the ACT-1 program was awarded to the Garrett-AiResearch Company on December 17, 1973, with the official go-ahead for January 2, 1974. The program structure is shown in Figure 1–2.

The responsibilities of the systems manager, Boeing Vertol, were (1) to approve the activities of the contractor, The Garrett Corporation, in the design and construction of the cars, (2) to coordinate the advisory efforts of the American Public Transit Association (APTA) and the

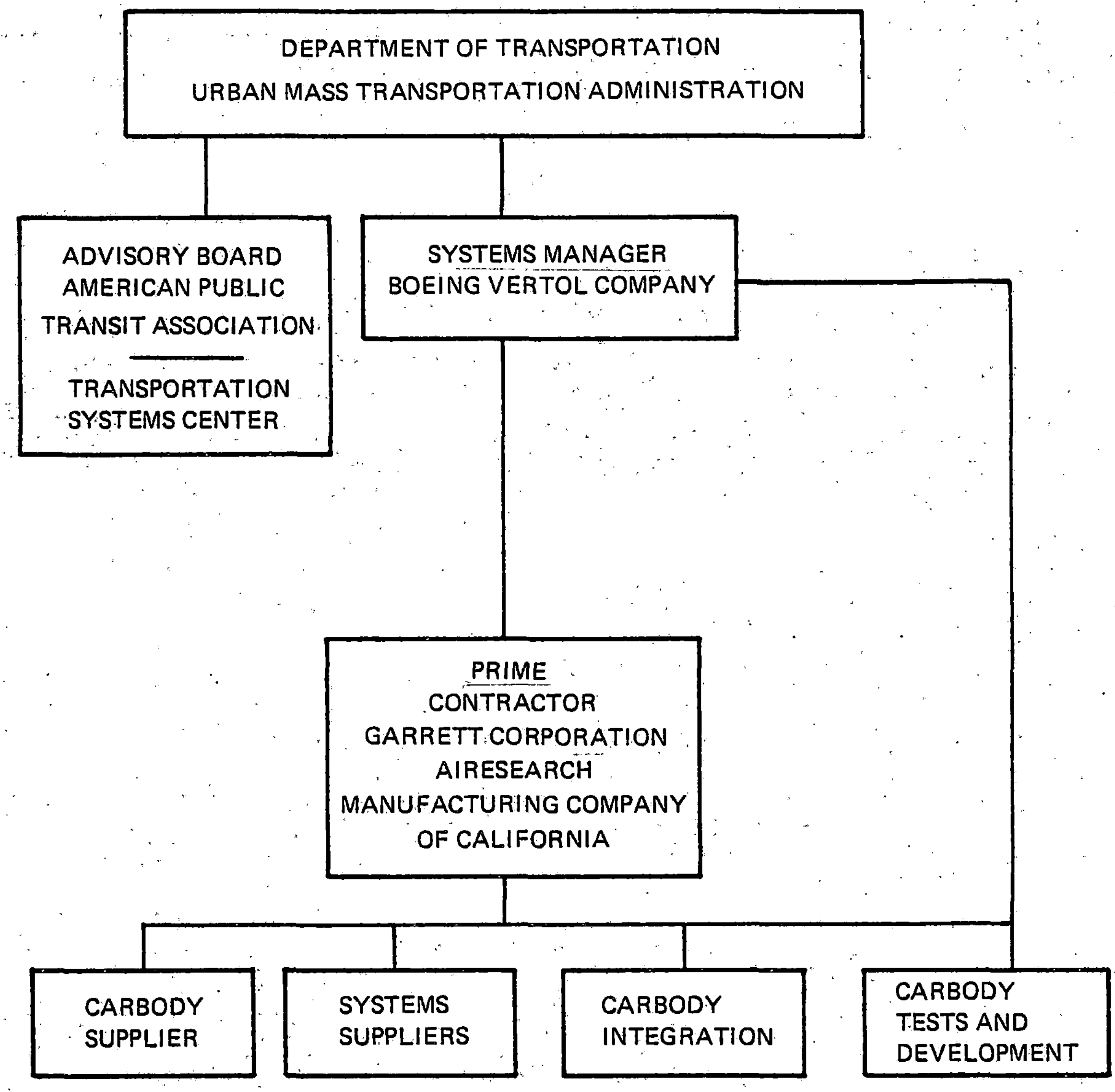


Figure 1–2. Program Structure

Transportation Systems Center (TSC), and (3) to report to the Urban Mass Transportation Administration of the Department of Transportation (DOT-UMTA) on the progress of the program.

The task of the contractor, The Garrett Corporation, was to acquire, assemble, and test the carbody and components, to conduct monthly design reviews with the systems manager and members of APTA and TSC, and to integrate the technical output of these meetings into the car design and development program.

1.3.2 Design, Fabrication, Functional Test

The interactions of the Garrett Corporation with the subcontractor during the design, fabrication, and functional test phases of the program are reported in Report No. UMTA-IT-06-0026-79-2.

1.3.3 Testing at Transportation Test Center (TTC)

1.3.3.1 Test Program Responsibilities at TTC

The Boeing Vertol Company, as systems manager for the URRVS Program, was responsible to the Urban Mass Transportation Administration for the ACT-1 Pueblo vehicle test program. As the principle ACT-1 subcontractor, the AiResearch Manufacturing Company had the responsibility to conduct all vehicle testing under the direction of Boeing Vertol up to and including the vehicle acceptance tests and to demonstrate satisfactory performance under the ACT-1 design specification. Following successful completion of the acceptance tests the Boeing Vertol Company took title to the ACT-1 cars for UMTA and assumed direct responsibility for the remainder of the test and demonstration program.

Boeing Vertol Responsibilities:

- Develop overall test plan.
- Prepare detailed test procedures and pass/fail criteria.
- Monitor and review test results of all tests.
- Determine suitability of the vehicle(s) to proceed to engineering testing based on the pass-fail criteria.
- Conduct the simulated demonstration and the acceptance/reverification testing.
- Maintain test logs.
- Coordinate and direct all test activities at TTC and provide interface with the TTC organizations.
- Schedule testing.

AiResearch Manufacturing Company Responsibilities

- Installation, operation, and maintenance of vehicle test instrumentation.
- Conduct of preparation/functional test, preliminary test/adjustment, engineering test, acceptance test under Boeing Vertol direction.
- Maintain test cars in operating condition throughout all test phases at Pueblo.
- Maintain and identify test vehicle configuration.
- Provide engineering support for all test phases.
- Release vehicles for testing (through acceptance test).
- Provide data reduction in accordance with the requirements of Boeing Vertol.
- Review and approve test procedures for preliminary test and adjustment, engineering, and acceptance test phases.
- Correction of defects disclosed by testing under the conditions of the contracts.

Joint AiResearch and Boeing Vertol Responsibilities:

- Develop status review including predicted facility and manpower requirements.
- Initiate and maintain vehicle log books.

Transportation System Center (TSC):

- Monitor technical progress and results for Urban Mass Transportation Administration.

Transportation Test Center (TTC)

The Transportation Test Center organizations monitored all ACT-1 test activities and provided the personnel for test controller, vehicle operators, power station operators, and track security for on-track testing. In addition, they provided personnel and facilities for maintenance, car weighing, wheel truing, and on-site data reduction. Dynalectron and ENSCO were the two major on-site contractors which provided support to the ACT-1 program.

The ACT-1 Pueblo test organization is shown in Figure 1–3.

1.3.3.2 TTC Test Facilities

The Department of Transportation Test Center, east of Pueblo, Colorado, provided all necessary facilities for testing and maintenance of rapid transit vehicles. Layout of the TTC is shown in Figure 1–4.

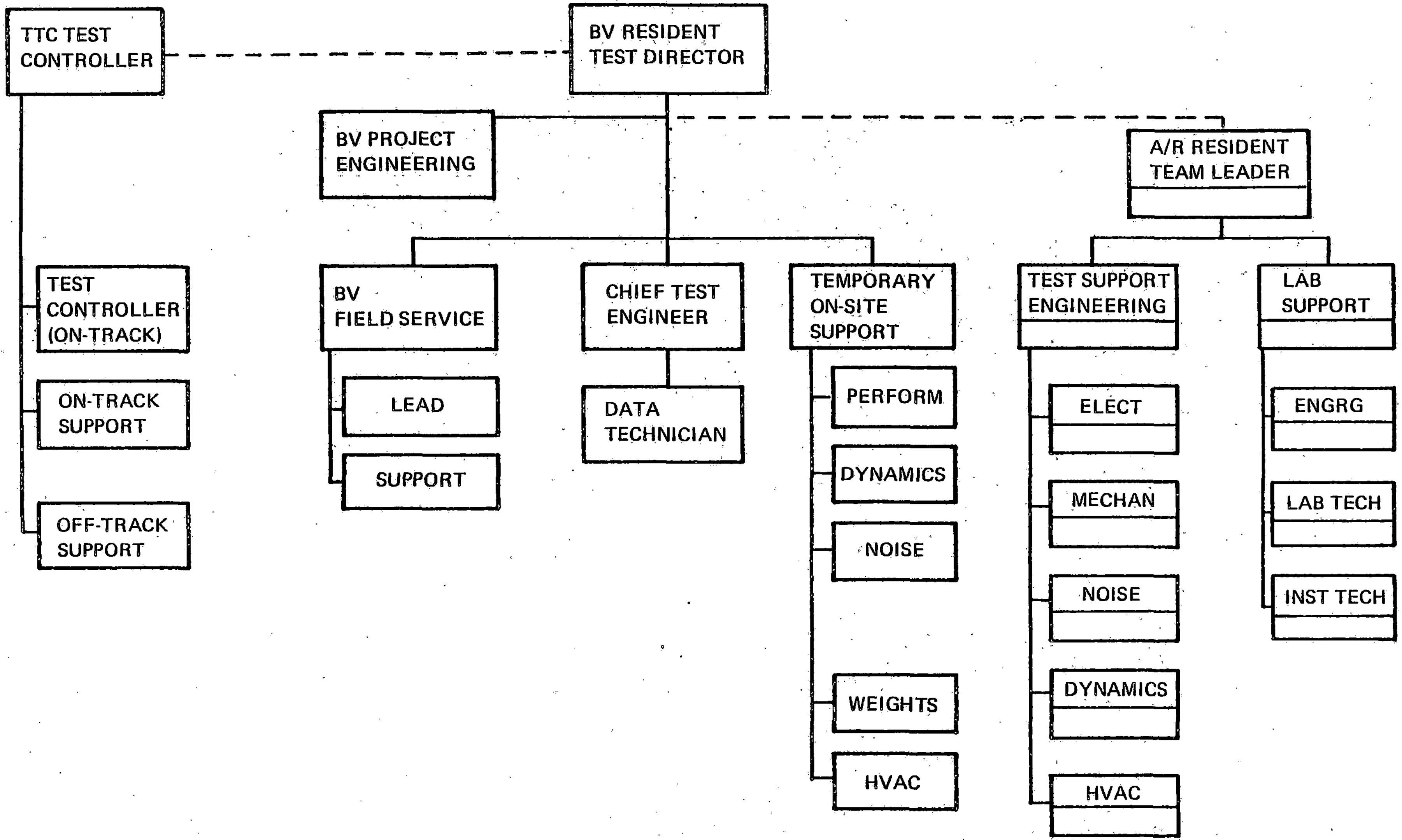


Figure 1–3. ACT-1 Pueblo Test Organization

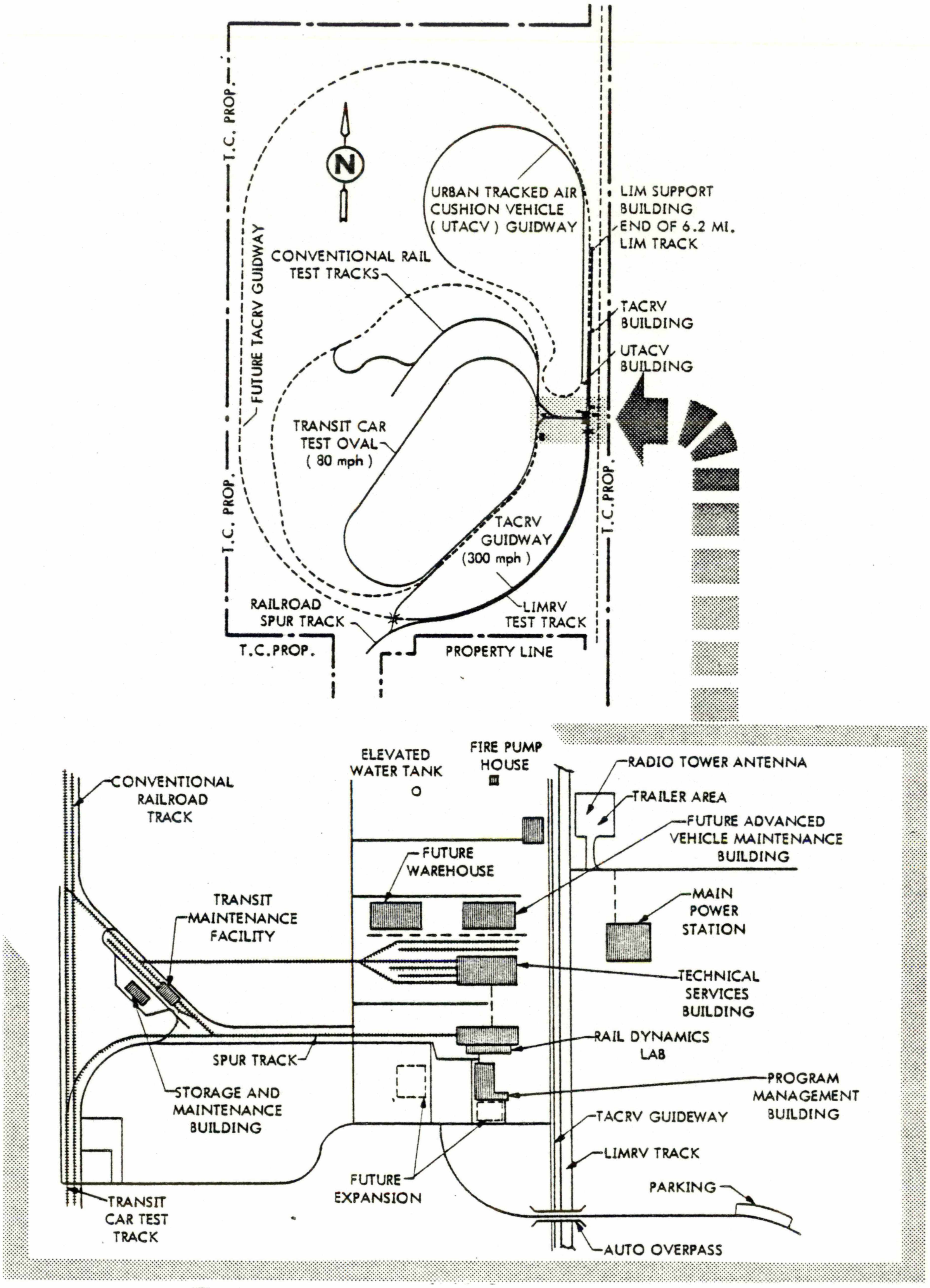


Figure 1–4. DoT High-Speed Ground Test Center

Testing was performed on the rail transit test track, a plan of which is included as Figures 1–5 and 1–6. The oval has a circumference of 9.1 miles, including 4,000 feet of level tangent track. It is provided with access spurs to the transit maintenance building and other areas of the TTC.

Power was supplied to the oval via a completely encircling third rail. This was fed from a transformer substation, the voltage being variable from the nominal 660vdc to 790v (no load). The transformer was normally adjusted to provide 600v under vehicle full-power acceleration. Running-rail and third rail details are shown in Figure 1–7. An overhead catenary wire system was installed from track station 279 to station 385. Its nominal height was 17 feet.

The Transit Maintenance Building (TMB) is situated as shown in the detail inset of Figure 1–4. It contains facilities for vehicle storage and maintenance. The structure encloses 150 feet of single track, half of which is above a full-track-width stand-up pit. The building also contains a power supply which provided 600vdc at up to 800 amps.* A scale was incorporated in the section of track which runs next to the TMB.

Storage space was available in the TMB for spares, etc. Lead ballast for loading the cars to weights corresponding to the various passenger configurations was also stored at the TMB.

Trailers situated close to the TMB served as offices for engineering personnel.

1.3.3.3 TTC Operating Procedures

Testing of the ACT-1 on the Transit Test Track (TTT) was conducted in accordance with the operating and test procedures described in the following documents:

1. Advanced Concept Train (ACT-1) Test Plan No. 6557, Revision A (Department of Transportation)
2. Operational Test Procedures, ACT-1 Test Program, dated February 18, 1977.
3. Standard Operating Procedures, Transit Test Track, Revision C, April 1978.
4. Railway Systems Handbook, HB5800.3A, dated September 10, 1976 (Transportation Test Center).

1.4 REPORT CONTENTS

This report documents the significant results of the ACT-1 test program conducted at the Transportation Test Center in Pueblo, Colorado, during the period of September 1977 through December 1978.

*This facility was updated to accommodate the ACT-1 requirements of 800 amps for startup and 560 amps for 3-minute power consumption.

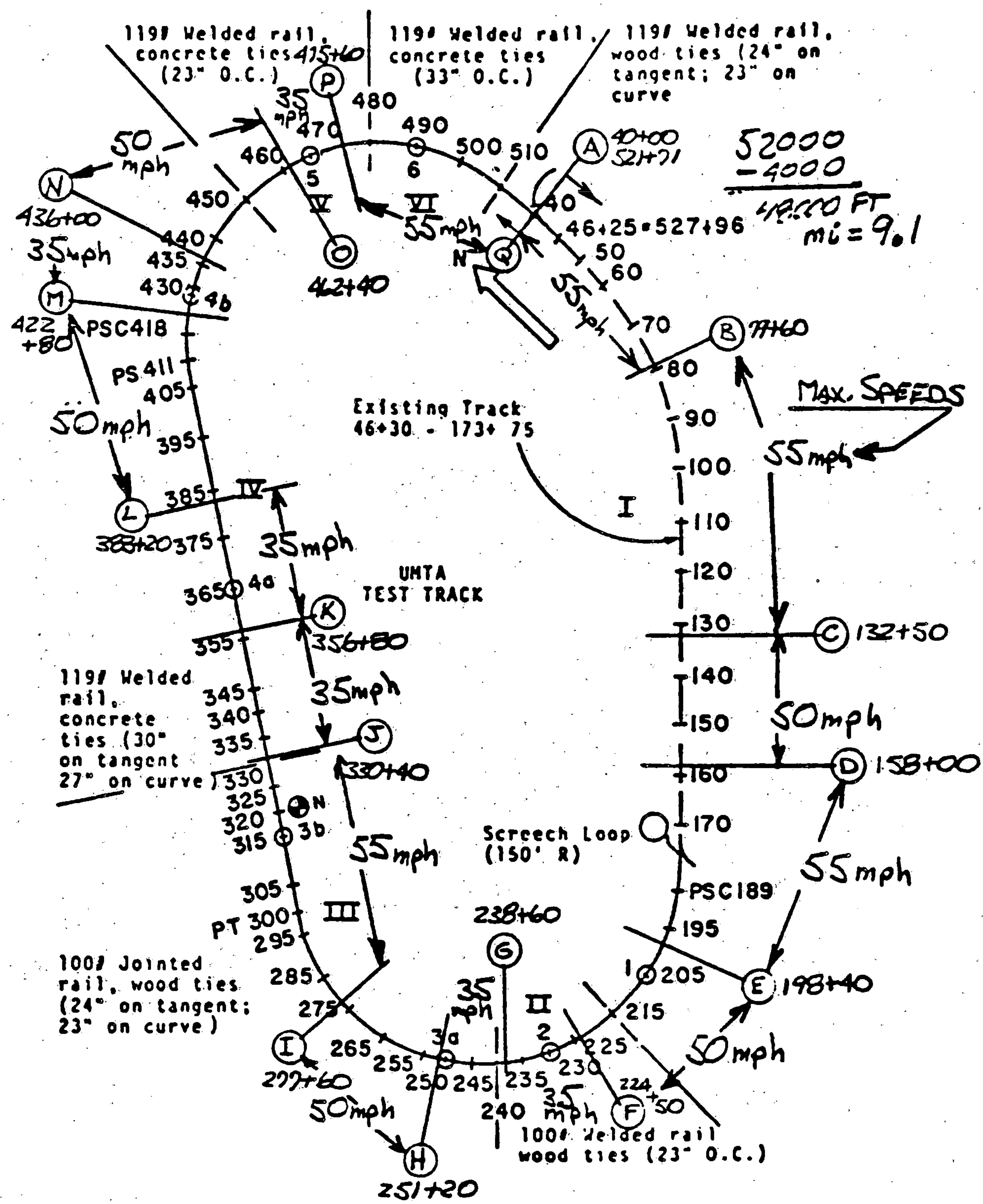


Figure 1–5. Transit Test Track

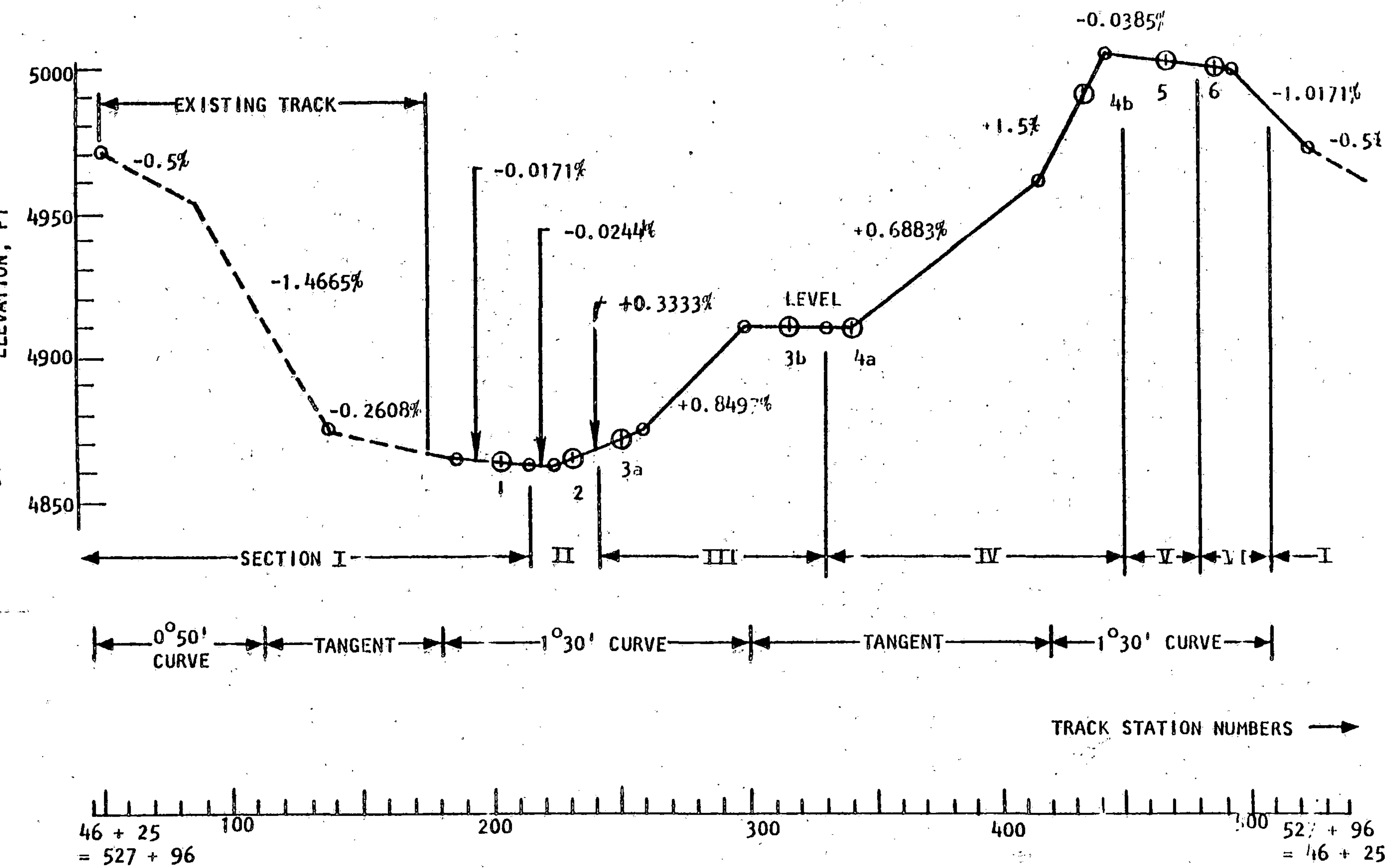


Figure 1–6. Track Profile, UMTA Rail Transit Test Track at HSGTC, Pueblo, Colorado

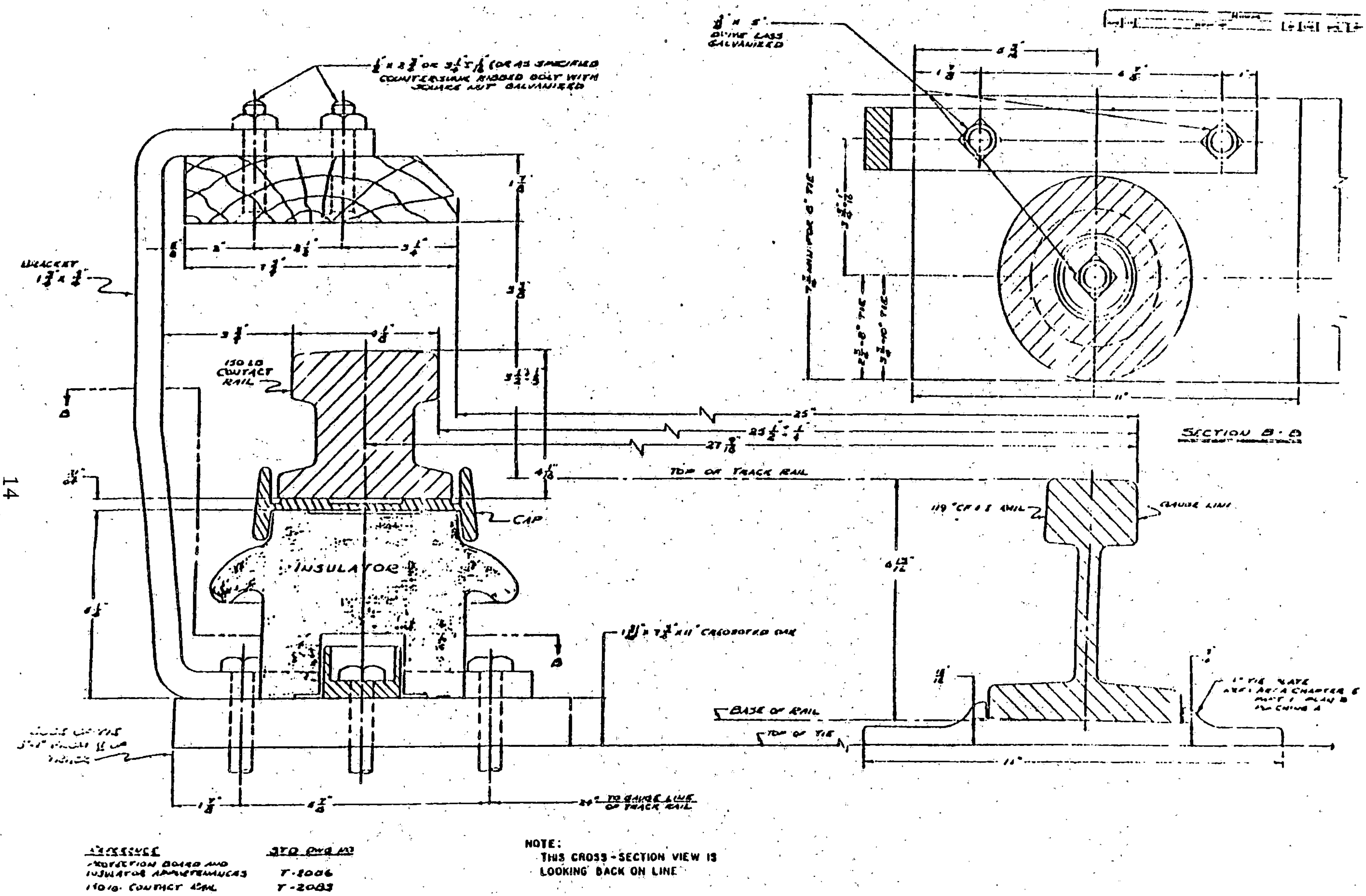


Figure 1–7. Contact Rail Assembly

A section on "VEHICLE CONFIGURATION" defines the basic vehicle as delivered to TTC. Configuration changes incorporated at TTC to meet performance requirements, facilitate maintenance, or improve operational characteristics or reliability have been summarized. Changes in performance parameters which resulted from changes in adjustable hardware such as gain potentiometers, pressure settings, etc, are not considered vehicle configuration changes and therefore are not included.

A series of tests was conducted during the early phases of the TTC test program called "PRELIMINARY TESTS AND ADJUSTMENTS." These tests were utilized to evaluate the interactions between various performance parameters and are recorded in Section 3.0 of this document. A change in a performance parameter such as acceleration rate may have an adverse effect on dead time or jerk rate and vice versa. The formidable task of iterating these parameters to obtain an acceptable overall performance of the ACT-1 cars is reported in Section 3.0. Additionally, miscellaneous tests such as crash attenuation and heating, ventilating, and air conditioning are included in this section.

Results of the engineering performance tests are presented in Section 4.0. These tests were conducted to establish the performance limits of the cars following the preliminary test and adjustments phase. Acceleration, deceleration, dead time, jerk rate, spin/slide efficiency, braking, and power consumption results are presented.

The vehicle ride quality characteristics and interior and wayside acoustic test results are presented in Sections 5.0 and 6.0, respectively. The maintenance demonstrations are described in Section 7.0.

The acceptance test results are summarized in Section 8.0.

1.5 CONCLUSIONS

The ACT-1 vehicle was subjected to a comprehensive test program at the UMTA Transit Test Center which resulted in confirmation of significant achievements in vehicle operating efficiency; technology advances in component design and integration; and of considerations for passenger safety, security, and comfort. As was to be expected in a program such as this, where innovation and departure from traditional techniques were strongly encouraged for the purpose of significant cost benefit improvement, some design features did not meet the design goals established. In retrospect, some design goals were overoptimistic and others, though attainable, did not warrant the continued expenditure of resources for the additional benefit to be gained.

An outstanding achievement was the operating vehicle energy efficiency. Measurements of energy consumption when operating on the synthetic transit route indicated that the energy storage units (ESU) of the vehicle provide a 48.6-percent propulsion system energy savings. This is in respect to an operational mode of the vehicles in which kinetic energy during braking is not recovered. A two-car train consist on a round trip of the synthetic transit route exhibited 7.12 kw-hr/car-mile energy consumption. As reported in the SOAC development program, the corresponding SOAC energy consumption was 12.43 kw-hr/car-mile. It should be noted, however, that this resulting energy savings does not relate directly to a proportional energy cost savings since the ACT I vehicle draws power at a greater peak demand than conventional systems when charging the ESU. The power cost rate is derived from both the total energy used and the peak demand during the period.

The vehicle was determined to be generally in compliance with the performance requirements and goals of the procurement specification. The acceleration performance met all of the specification requirements except that the initial acceleration rate exceeded the nominal value by more than 5 percent for some runs. The acceleration and deceleration levels were proportional to the control input level throughout the control range. Test results confirmed that vehicle performance during braking and parallel off-line drive conditions was unaffected by power isolation gaps.

The automatic speed regulation system held the car speed within ±2 mph of the selected speed over grades up to ± 1.5 percent in all but a few runs. In general, slip/spin efficiencies, as measured in acceleration and deceleration conditions, fell short of specification requirements. The levels of efficiencies, however, are believed to be within the state of the art.

A few problems were evident in the braking performance data. For blended braking stops from approximately 70 mph and greater, the energy stored by the ESU was large enough that the ESU reached its maximum speed before the car was stopped. When the ESU reaches its maximum speed, electric braking cannot be maintained and the friction brakes do not blend in soon enough to keep the deceleration rate from momentarily dipping down. Also, the emergency braking rate varied depending upon initial car speed. The braking rate for a 130,400-pound gross weight was generally 0.2 mphps less than for a 98,000-pound gross weight vehicle. The maximum recorded brake lining temperature measured was 935°F, which compared favorably with earlier dynamometer simulation tests of 1,040°F, from which the lining was proven to be still serviceable after occasional brief exposure.

ACT-1 interior noise levels were generally within acceptable limits throughout the car over the speed range from 0-80 mph. Interior levels were comparable to other recent rail transit vehicles. Where ACT-1 noise levels exceed those of other rail cars, it is in the speed region of 25-50 mph; with levels at 35 mph, 5 dBA higher than contemporary cars. This results from the varying rotational speed characteristics of the energy storage units which also produce occasional beating within the center module of the cars.

Wayside noise of the ACT-1 cars was considered to be only marginally acceptable, since the cars did not achieve established goals except at 80 mph. Below this speed, noise levels exceeded the criteria as a direct result of energy storage unit noise levels. Quieting of this one system would have required substantial additional acoustical treatment in the ESU bays and was considered unwarranted for this program.

The ride quality achieved was generally considered good. Carbody vertical vibrations at the rigid-body suspension frequencies (1 Hz to 2.5 Hz) and carbody bending frequencies (6.5 Hz to 14 Hz) were close to meeting the vertical ride quality specification. This specification is more stringent than the State-of-the-Art Car (SOAC) ride quality requirements. ACT vertical vibrations were significantly lower than those measured on SOAC and would meet the SOAC goal. Lateral carbody vibrations, however, are significantly above the specification requirement. These data would not meet the SOAC goal and were higher than SOAC levels at comparable speeds and carbody locations.

The ACT-1 car weight grew rather significantly from a program concept weight of 76,000 pounds in 1973 to an actual weight of approximately 92,000 pounds. This weight increase was primarily in the carbody system and the ESU. Some success was achieved in weight reduction of individual systems, the truck being one which is notable. Total weight of the truck assemblies is 26,516 pounds per car set, representing a weight savings of 6.5% when compared to the state-of-the-art truck assemblies which were classified as lightweight trucks. Overall, the truck assembly proved to be a significant advancement considering ride performance, unit weight, and maintainability features. Truck design allows removal of discrete components such as wheels, ground brush rings, and axle shafts without detrucking or truck disassembly and without the use of the conventional heavy equipment associated with truck maintenance.

The carbody system met new safety requirements never before achieved for collision attenuation. Data was obtained that verified collision attenuation system characteristics. It is concluded that the system provides a more gentle deceleration than predicted for impacts of 5 mph or less.

The heating, ventilating and air conditioning system (HVAC) performance tests were conducted at the Transportation Test Center under actual weather conditions to verify proper system operation and to substantiate performance. The test data verified that the capacity of the heating system was adequate to meet the cold day heating requirements. The air cycle air-conditioning system, as installed, was inadequate. It was concluded that the car distribution system and insulation were inadequate and that the air cycle system should be considered for future transit car applications to reduce weight and ease maintenance.

The interior fabrics and liners met the stringent flame-resistant and low-smoke-emission qualities of the transportation systems center guidelines for flammability and smoke emission, TSC-75-LFS-4. The lightweight monomotor truck performed trouble-free except one zurn coupling failure caused by improper lubrication.

The flush-plug, biparting-door design presented insurmountable problems and this design may be unacceptably complex for transit vehicle usage.

2.0 VEHICLE CONFIGURATION

The ACT-1 vehicle is a self-propelled car having a control module (or cab) at one end; it is designated an A-car. Two A-cars were built and are shown in Figure 2–1.

The cars are designed for use in frequent-stop, high-speed, intracity mass transportation. The cars are identical except for the interior seating arrangement. The cars are designed to operate as a two-car consist; however, they can be operated separately, for test purposes. Power input is a nominal 600vdc supply that can be accepted from a third rail or pantograph. The cars can reach 80 miles per hour in 52 seconds and power consumption was reduced by use of the on-board flywheel energy storage units; for this reason they can reach any typical subway station following a power loss. Despite the high energy content of the energy storage units, the cars have low interior and exterior noise levels—even at 80 miles per hour. Although there is no requirement at the present time to demonstrate these cars on existing properties, the cars have been designed for use in New York, Boston, Cleveland, Chicago, and Philadelphia. Transition from third-rail power to catenary power can be made automatically with no need to stop the car.

2.0.1 GENERAL DATA

Length over couplers	78 ft 0.5 in.
Width (maximum)	9 ft 11.25 in.
Height (maximum)	11 ft 3.375 in. to 11 ft 9.5 in.
Track gauge	4 ft 8.5 in.
Minimum radius	145 ft
Track voltage	450 to 750v; 600v nominal third rail or catenary
Doors (number per side)	3
Height of opening	6 ft 5 in.
Width of opening	50 in.
Floor height	
Minimum	43.875 in.
Maximum	49.5 in.
Seats	
High-density car, seated	36
Standee units	32
Nominal	100
Maximum	278
Low-density car, seated	56
Nominal	100
Maximum	235

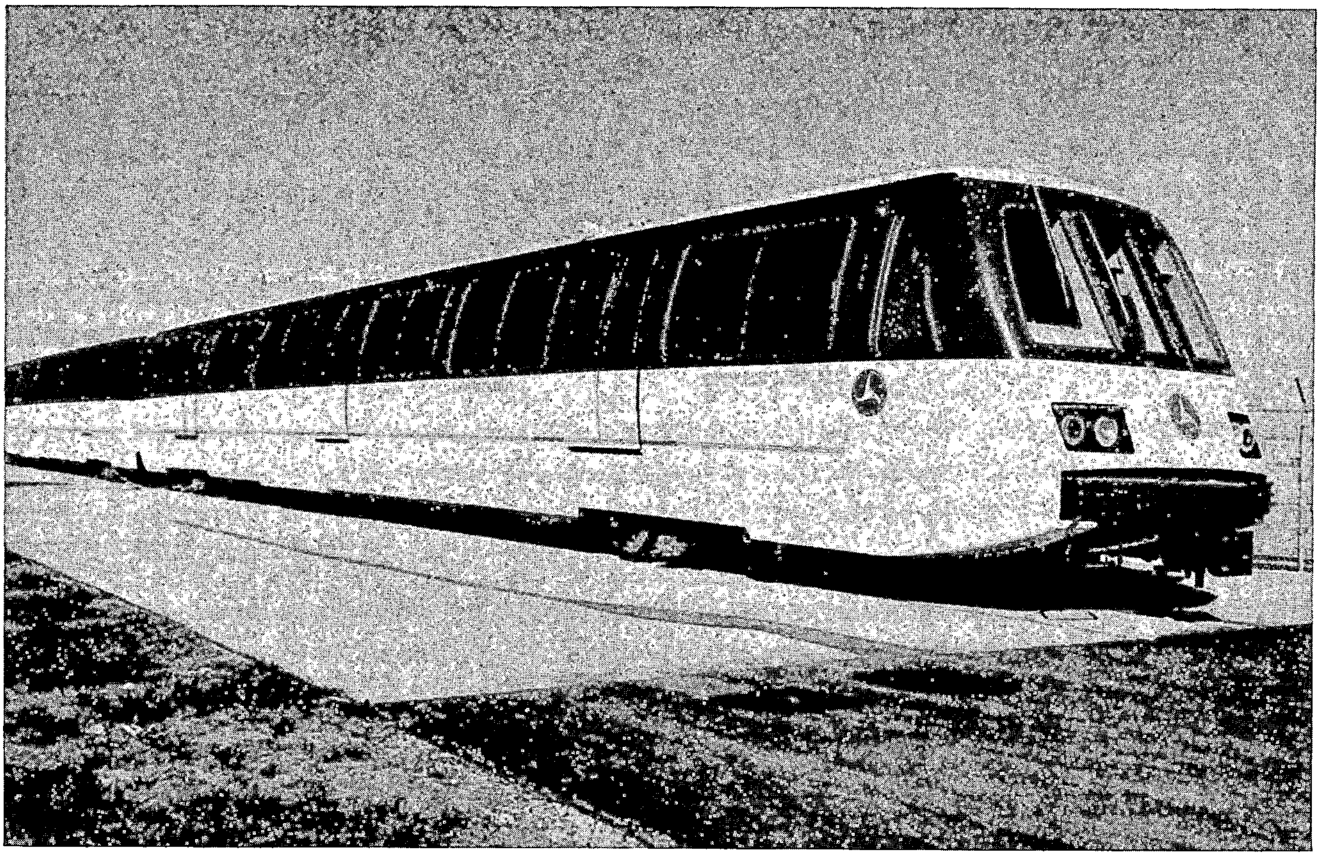


Figure 2–1. The Advanced Concept Train (ACT-1)

Trucks and Suspension

Type	Casting/wrought members, welded assembly frame, balljoint equalization
Drive system	Monomotor, enclosed drive train, nonrotating axle housings
Wheels and axles	Removable wheels, full floating removable axle shafts
Suspension	Stiff rubber primary, air bags in secondary, nonlinear damping
Weight	13,000 lb less traction motor

Friction Brakes and Pneumatics

Type	Air-operated, chrome-copper, caliper disc
Number	2 discs per axle
Mounting	Inner wheel hub
Air supply	150 psi nominal, 25-cfm shaft-driven compressor
Reservoirs	1 main, 2 brake supply
Control	Electropneumatic analog; slide protection

Propulsion System

Continuous traction power	800 hp per car
Number of traction motors	2
Total energy storage at 100-percent rpm	9.0 kw/hr per car
Usable energy at 70 to 100-percent rpm	4.6 kw/hr per car
Number of storage units	2

Carbody

Underframe	Aluminum side sills, cross bearers, draft sills, and center shear panels
Shell structure	Aluminum door and window posts, seat rails, and roof rails; steel collision posts

Sheathing	Fiberglass-aluminum honeycomb panels with stainless-steel facings
Cab and "B" end	Polyester-resin-reinforced fiberglass
Sheathing	Fiberglass, molded
Exterior finish	Polyurethane paint
Collision protection	Coupler, movable anticlimber with hydraulic and expendable shear pin attenuation

Door System

Type	Flush plug, biparting
Actuation	Pneumatic operators
Sealing	Neoprene
Control	Electric from cab or remote passenger-operated pushbuttons

Heating, Ventilating, and Air Conditioning

Type	Modified air cycle
Power	Shaft-driven from flywheel through a fluid clutch
Capacity (total car)	17.8 tons at turbocooler design rpm
Airflow (hot-day design)	
Total	4,170 cfm
Fresh	1,670 cfm
Fan types	400 Hz, normal 32vdc, emergency
Heaters	Duct heaters plus floor strip
Weight	1,300 lb

Auxiliary Power

Type	Nominal 400-Hz oil-cooled alternators
Voltage	127 to 220v three-phase
Power source	Flywheel-driven
Control	Variable frequency

Communications and Train Control Features

Train control	Manual, speed regulation
Communications	Closed-circuit TV, passenger intercom, automatic station announcements, and public address radio

Interiors	Polyester-resin-reinforced fiberglass with flame-retardant additives; modular molded panels

Performance

Maximum operational speed	80 mph
Nominal initial acceleration	3.0 mphps
Nominal deceleration	3.0 mphps
Emergency deceleration	3.5 mphps
Jerk rate	2.0 mphpsps
Energy consumption	7.2 kw-hr/car mile
Power	600vdc nominal
Empty weight	92,000 lb
AW3 weight	133,700 lb (high density) 127,250 lb (low density)

2.0.2 EXTERIOR FEATURES

The exterior of the car features large, double-glazed windows, three pairs of biparting, sliding-plug doors on each side, a smooth flush exterior with no exposed fasteners, and a heavy anti-climber with collision attenuation on each end. The roof portion over the forward truck has permanently attached fittings to which a pantograph can be secured for overhead current collection as an alternative to the truck-mounted current collectors.

The A end, which is the control module, is sheathed in molded fiberglass, has large windshields of impact-resistant safety glass, and a door that is used mainly for an emergency exit. A loop step is supplied on the anticlimber to enable entry through this door by crew members and maintenance staff. Light assemblies recessed into the surface contour contain headlights and taillights. The B end, also sheathed in fiberglass, has a sliding door for crew entry and intercar traffic flow.

2.0.3 INTERIOR FEATURES

The interior of the cars has been designed to ensure a reliable, efficient, and safe interface between man and equipment, with particular attention paid to the aged and handicapped. As can be seen in Figure 2–2, one of the cars has a high-density interior arrangement, which is intended for use in subways where the typical length of the passenger's journey rarely exceeds 20 minutes. The other car, the low-density version, is intended for journeys of more than 20 minutes; consequently the seats have a greater degree of comfort and support, and standee space is minimal.

The interior panels are polyester-resin, fiberglass-reinforced plastic (FRP) of modular design to allow interchangeability from one part of the car to another and from an A car to a B car. The resin of the FRP has additives that give exceptional fire-retardant and low-smoke characteristics.

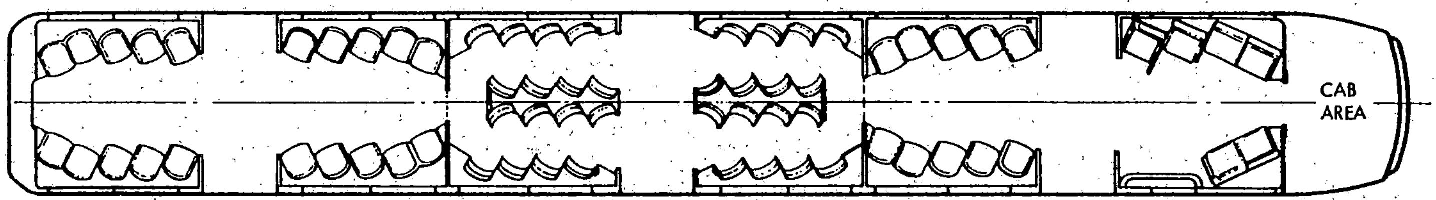
The seats in both the high- and low-density cars are cantilevered from the wall and the lounge seats in the center of the car are the pedestal type (see Figure 2–3). This gives the car an air of spaciousness and improves the access to the floor surface for carpet-cleaning appliances, thereby reducing maintenance costs. Eliminating the aisle support for the seats also increases passenger safety (by reducing the chance of tripping) and allows increased mobility of the boarding and departing passengers. Even greater ease of passenger mobility is achieved by angling the perimeter seats. A passenger at this location faces the general direction of the doors, and no seat is more than 12 feet from a doorway.

For the elderly and handicapped, one end of the high-density car is equipped with seating designed for their particular needs. This design includes special handrails, space for wheelchairs, high- and short-seat chairs, and crutch holders (see Figure 2–4).

2.0.4 EQUIPMENT

The general arrangement of the ACT-1 equipment is shown in Figure 2–5. The undercar is sectioned into longitudinal bays which are further subdivided into three lateral bays. The side bays generally contain the HVAC packs and most of the power control gear; in addition, heater contactors are included in these bays. Forward and aft of the A-end truck, equipment is attached to the underframe, covered only by the hinged side skirts. The dead battery start panel and resistor are located on the left in Bay 1A, and the pantograph control box is located on the right in Bay 1C. The electropneumatic brake unit and reservoirs are located behind the A-end truck, forward of the B-end truck. On the right side, in an enclosed bay (13C), is the battery; on the left side (Bay 13A) is the low-voltage power supply. Located in the center bays of the car are the energy storage units, the air compressor, the input inductor, and the line breaker.

Interior equipment is located primarily in the cab and the B-end bulkhead. Located in the control module are communications equipment, power supply, low-voltage distribution panels, door relay panels, miscellaneous breakers, train control equipment, and temperature controls. Located in the B end of the car are the monitor panel, ECU assembly, trainline panel, coupler control, interior CCTV camera, and hostler control.



FULL COMPARTMENT

SEATS 20
NOMINAL CAPACITY . . 40

SUPPORTED STANDEE

SUPPORTS 32

HALF COMPARTMENT

SEATS 10

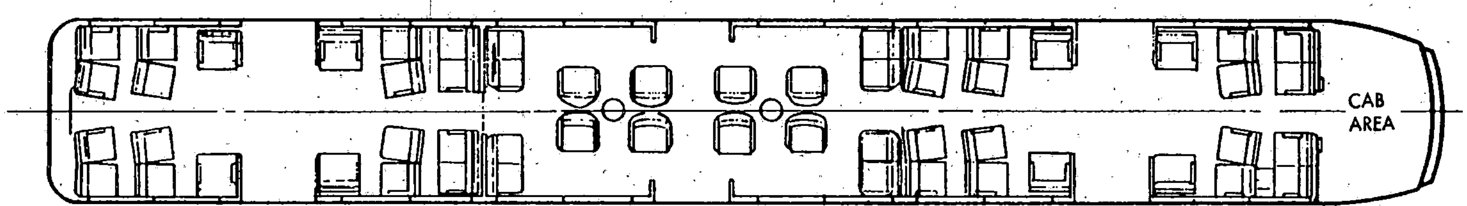
ELDERLY AND HANDICAPPED

SEATS 6
WHEELCHAIR SPACE. 1

36 SEATS, 32 SUPPORTS

NOMINAL CAPACITY = 90

DOTX-5



FULL COMPARTMENT

SEATS 20
NOMINAL CAPACITY . . 36

LOUNGE

SEATS 16
NOMINAL CAPACITY . . 24

FULL COMPARTMENT

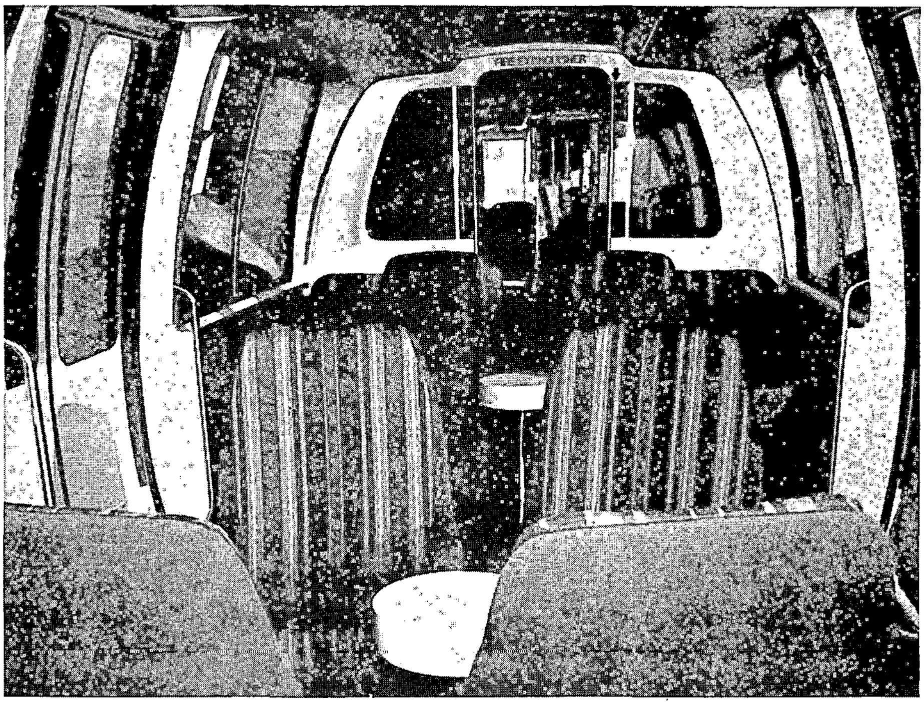
SEATS 20
NOMINAL CAPACITY . . 36

56 SEATS - NOMINAL CAPACITY = 96

DOTX-4

Figure 2–2. Seating Arrangements

A. HIGH-DENSITY CAR INTERIOR



B. LOW-DENSITY CAR INTERIOR

Figure 2–3. Interior Configurations

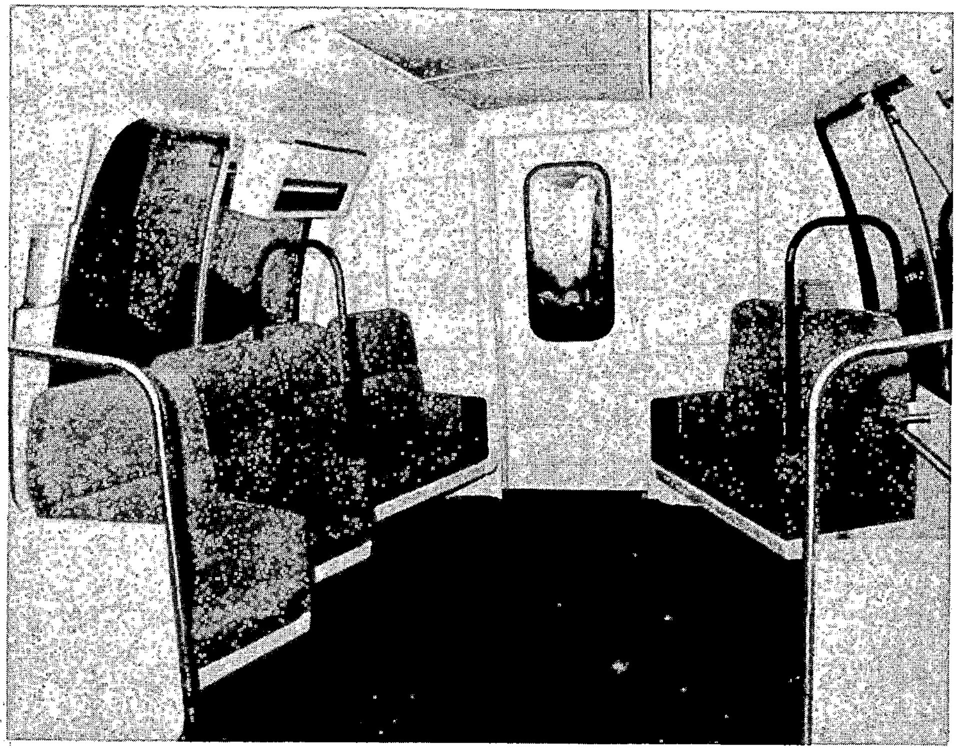


Figure 2–4. Elderly and Handicapped Section

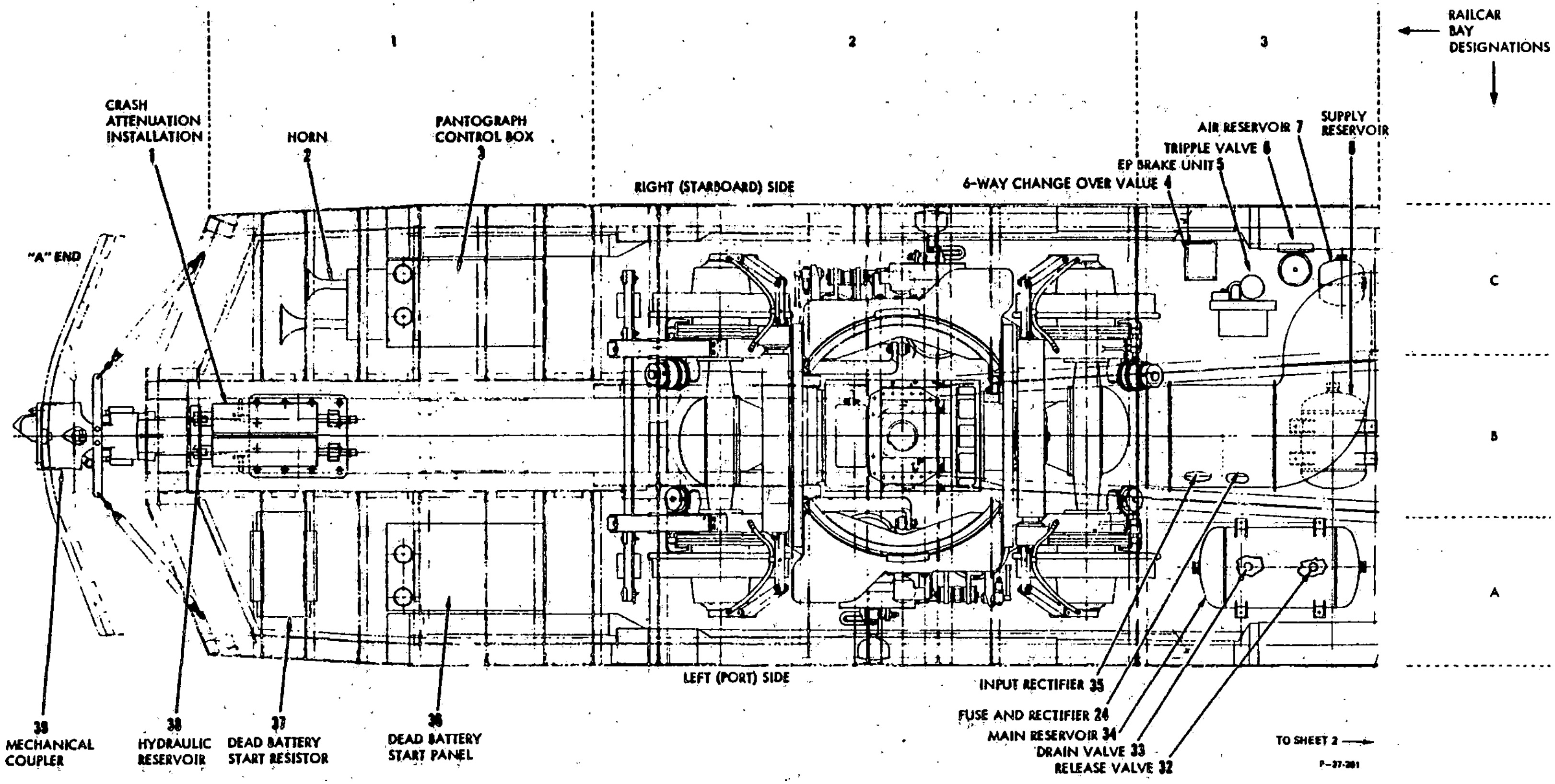


Figure 2–5. Undercar Equipment (Sheet 1 of 3)

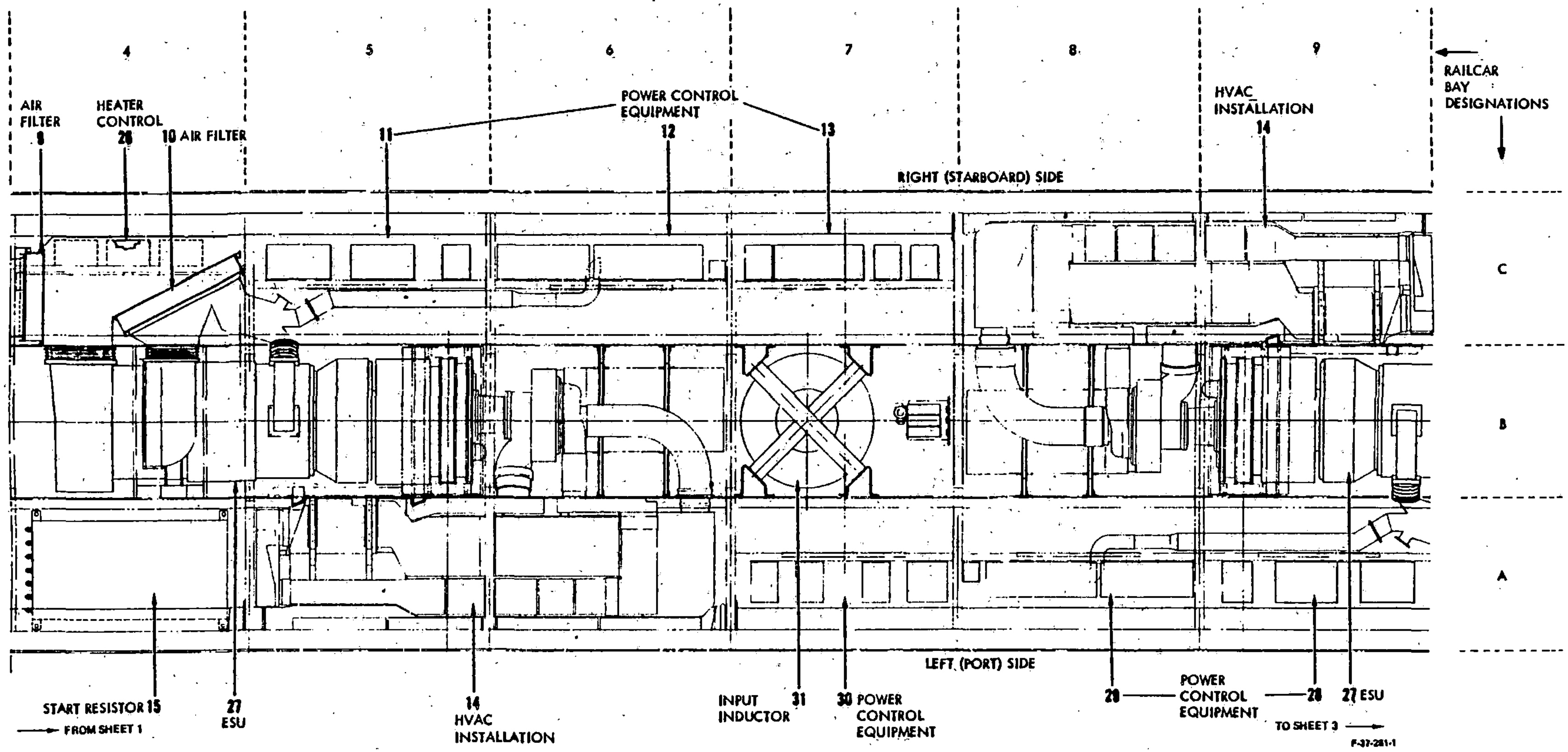


Figure 2–5. Undercar Equipment (Sheet 2 of 3)

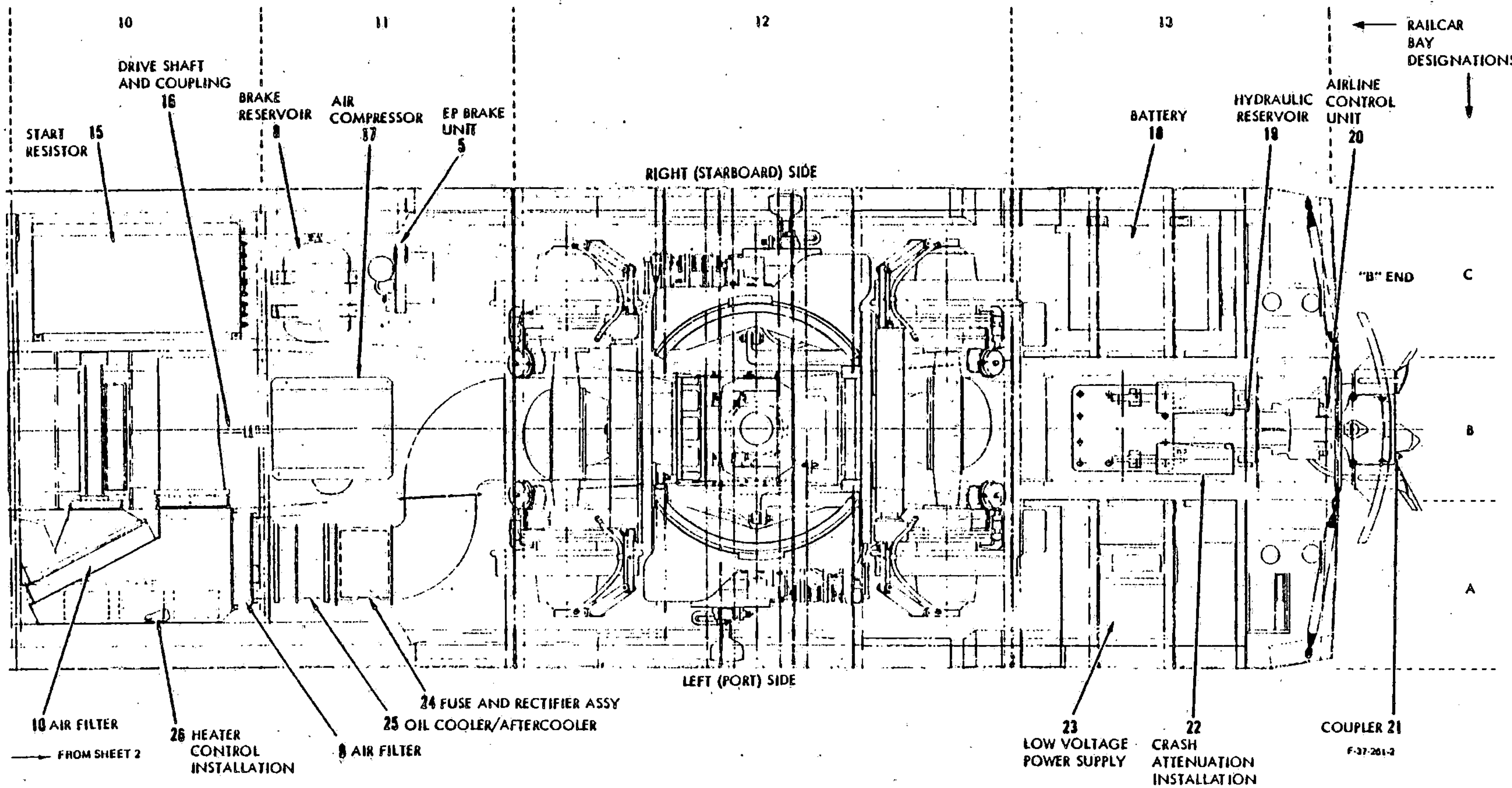


Figure 2–5. Undercar Equipment (Sheet 3 of 3)

2.1 CARBODY

2.1.1 Carbody Description

The ACT-1 carbody structure (see Figure 2–6) consists fundamentally of a welded-aluminum-extrusion frame. The side panels and roof consist of molded sandwich structure having fiberglass inner and outer skins with a stainless exterior facing. The side panels have an aluminum honeycomb core while the roof core is a resin-reinforced cellular paper. The skirt panels which provide access for the undercar equipment are fabricated of stainless steel with fiberglass backing. Fiberglass belly pans are installed beneath the undercar equipment bays.

The subfloor consists of an aluminum skirt and plate structurally fastened to the underframe. The primary floor is made of plywood with aluminum face sheets and is isolated from the subfloor and primary structure with elastomeric mounts. Acoustic treatment in the floor area consists of aquaplas spray in selected undercar bays, Baryform over subcarpet, and Baryfol BMIC between floors. The entire floor is covered with carpeting.

The carbody side, side door, cab side (drop sash), and B-end door windows are double-glazed. The inner glaze is a clear laminated safety glass and the outer glaze is a polycarbonate with an MR4000 coating with bronze tint. The cab windshield and cab emergency door windows are single-glazed, fixed-type, laminated safety sheet.

There are three biparting plug-type doors on each side for passenger entry and exit. These doors are pneumatically actuated with a manually operated emergency release. The A-end door (between cab and passenger compartment) is a hinged-type door that opens into the cab. The cab emergency exit door is a manually operated, hinged, single-leaf door with a lock. The B-end door is a single-leaf, manually operated, sliding type with a lock.

The A and B ends of the ACT-1 incorporate collision attenuation systems which permit the vehicle to sustain low-speed end impacts without permanent structural damage. In such impacts, the vehicle energy is absorbed by hydraulic cylinders which are actuated by a sliding coupler carrier assembly structure attached to the anticlimber. Except for replaceable shear pins, the system is fully reusable and requires no external energy source. The ACT-1 is equipped with conventional couplers which are identical except that the B-end coupler includes an electrical coupler for trainline functions. The coupler and anticlimber are both attached to a carrier assembly which is restrained by shear pins which must fail before the collision system is actuated. The collision attenuation system installation is shown in Figure 2-7.

A double-arm scissor-type pantograph located on the railcar roof on the A-end provides for catenary operation when raised. It is lowered and locked down when operating on third-rail power.

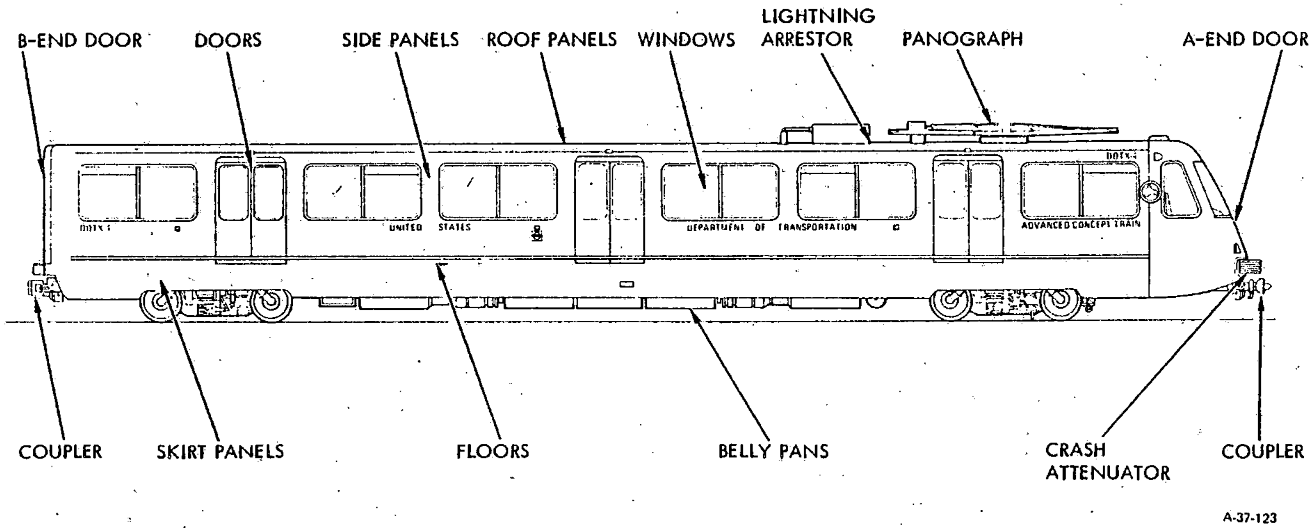


Figure 2–6. ACT-1 Carbody

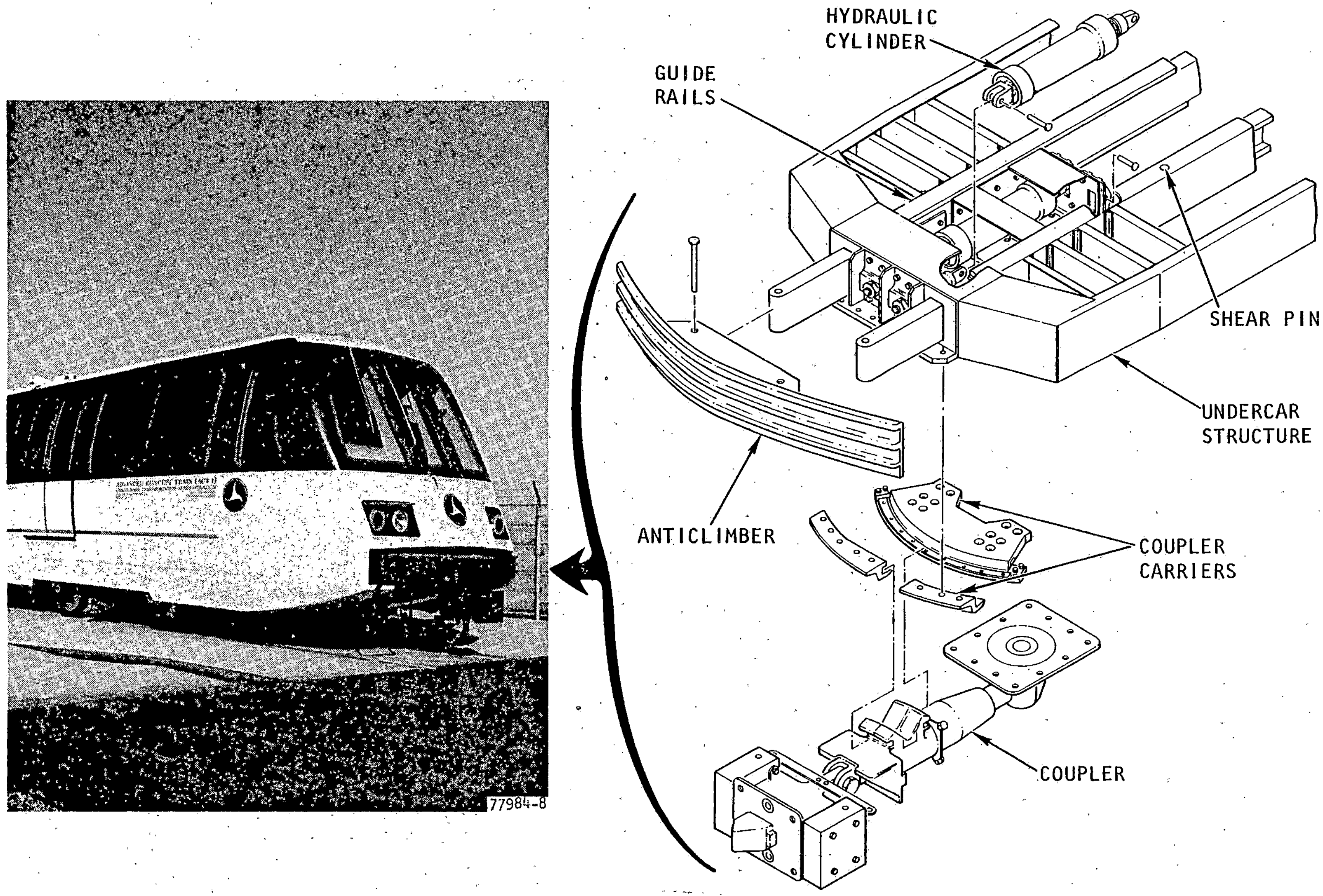


Figure 2–7. Crash Attenuation Components

A 3.0 kv lightning arrestor is provided on the railcar roof near the pantograph. This arrestor will dissipate any lightning electrical surge. The ground lead for the arrestor is attached to a main framing member at the roof.

2.1.2 Final Configuration

The ACT-1 vehicles as delivered to the Transportation Test Center (TTC) are defined by drawing 2000112-1 for DOTX-4 and 2000112-2 for DOTX-5. The test program at TTC necessitated some carbody changes which are described below to define the final carbody configuration as delivered to UMTA upon completion of the TTC test program.

2.1.2.1 Cab Destination Sign

The cab destination sign, drawing 2017338-1, was an obstruction to test personnel working on the left side of the cab so the sign was removed. Because property demonstrations have been cancelled, the destination signs are no longer required so the destination sign has not been replaced.

2.1.2.2 Bay 7B Belly Pan

The Siemens breaker in bay 7B would frequently hang up during early phases of the test program and would require a manual reset. As designed, the belly pan under bay 7B would have to be removed to reset the breaker. In order to facilitate testing on the track, the belly pan on bay 7B (Avis drawing 26-45000-513) was modified to install a hinged trap door for easy access in resetting the Siemens breaker without removing the belly pan. The modification was per Project Authorization 115553 and is shown in Figure 2-8.

2.1.2.3 A-End Coupler

The coupler adapter on the TTC locomotives which mates with the ACT-1 coupler does not have an air supply plumbed to the adapter. A hose, external to the coupler, supplies the brakepipe air from the locomotive to the ACT-1. Therefore, the ACT-1 couplers were modified to install a mating hose compatible with the TTC locomotive, as shown in Figure 2-9.

The A-end coupler on the ACT-1 provided only manual uncoupling. It became increasingly difficult to manually uncouple from the locomotive adapter so an airline and valve were connected to the A-end coupler actuator, as shown in Figure 2-9, to permit pneumatic uncoupling. No formal drawings were prepared for these coupler modifications.

2.1.2.4 Taillights

The ACT-1 cars were designed to operate in a two-car consist during property demonstrations and therefore no provisions were made for running lights on the B end. The test program at TTC necessitated running single-car operation and therefore lights were required on the B end.

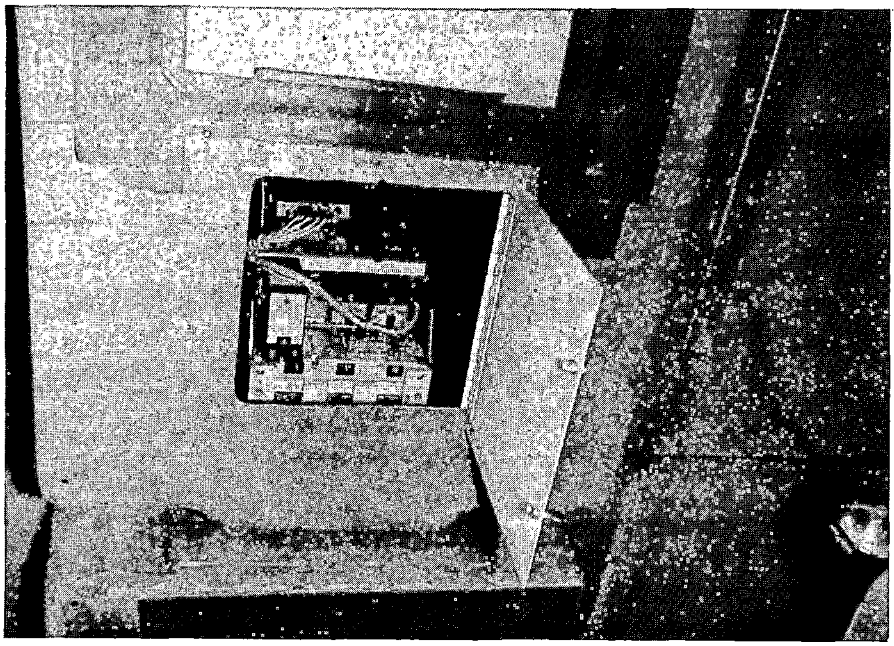


Figure 2–8. Siemens Breaker Access Door

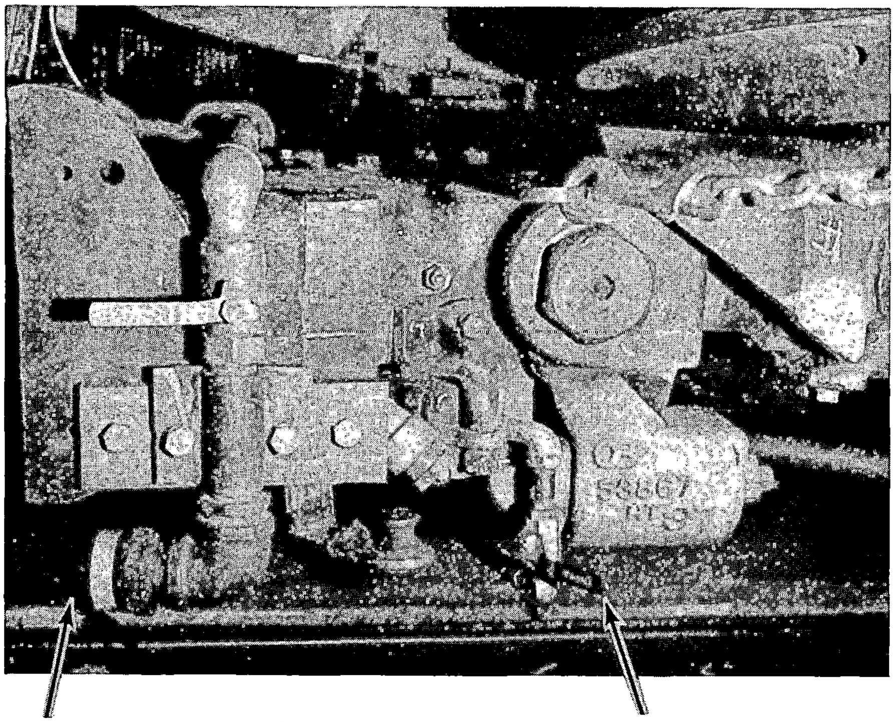


Figure 2–9. Coupler Modifications

A red-and-white light powered by a 12-volt automobile battery was installed on the B end of each vehicle as shown in Figure 2-10. No formal drawings were prepared for this installation.

2.1.2.5 Skirt Panel Fasteners

The equipment bay skirt panels were originally secured with clip-in 1/4-turn Dzus fasteners with a screwdriver-slotted head. Early maintenance activities at TTC indicated the slotted heads required excessive time to remove or install. A change was made to a Dzus slip-on 1/4-turn fastener which has a wingnut head for easy operation without tools. Two different-sized wingnut fasteners were used with Dzus part numbers AW6T13 and AW6T26. Several locations would not accommodate the different type retainer required for the wingnut-type fasteners so the slotted-head fasteners were retained in those locations (about 10 percent of the total fasteners). A typical installation of the wingnut-type fastener is shown in Figure 2-11.

2.1.2.6 Collision Attenuation

The hydraulic cylinder for the A-end collision attenuation system is designed with a tapered metering pin to provide a softer impact at low speeds. This feature results in approximately 10.5 inches total anticlimber displacement for a 5-mph impact into a rigid barrier. The collision-attenuation-system test program at TTC required a 5-mph impact into a rigid barrier. Pretest clearance checks revealed that the floor extension plate on the anticlimber (AVCO drawing 26-31068-7) and angle plate (AVCO drawing 26-31068-3) had insufficient clearance from the primary structure for the expected stroke. The extension plate and angle plate were cut away locally as shown in Figure 2-12 to provide the required clearance for the collision attenuation test on DOTX-5. DOTX-4 has not been modified.

2.1.2.7 Skirt Panel – Bay 13C

The skirt panel which provides access to the battery compartment in bay 13C was originally secured to a side skirt support assembly (AVCO drawing 26-31011-76) with 10 Dzus fasteners. The side skirt support assembly had to be removed before the battery could be rolled out for servicing. In order to facilitate battery servicing, the support assembly (26-31011-76) was removed and a clip angle with Dzus fasteners was installed at each end to provide skirt restraint. The forward clip angle is shown in Figure 2-13.

2.1.2.8 Final Configuration Summary

The final carbody configuration changes are summarized in Table 2-I.

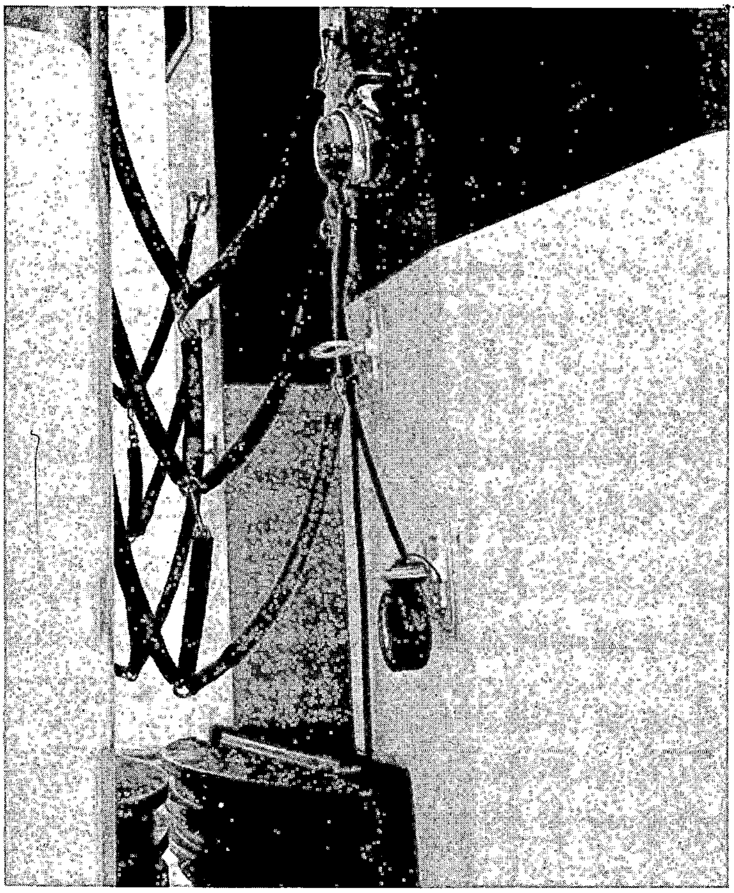


Figure 2–10. Taillight Installation

Figure 2–11. Wingnut Dzus Fasteners

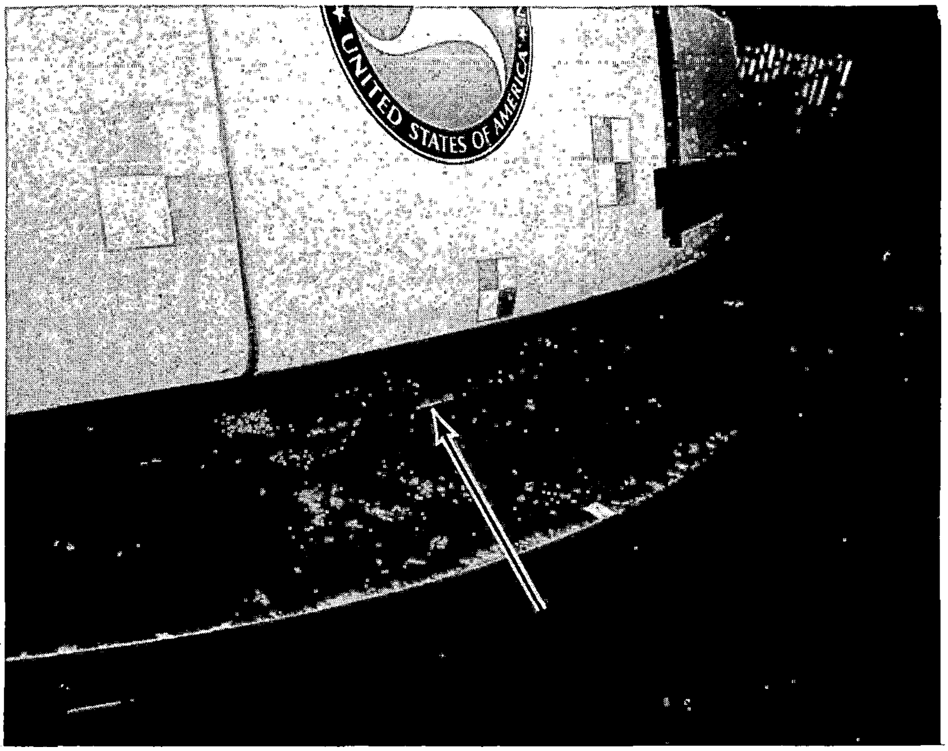


Figure 2–12. Floor Extension Plate Modification, DOTX-5 Only

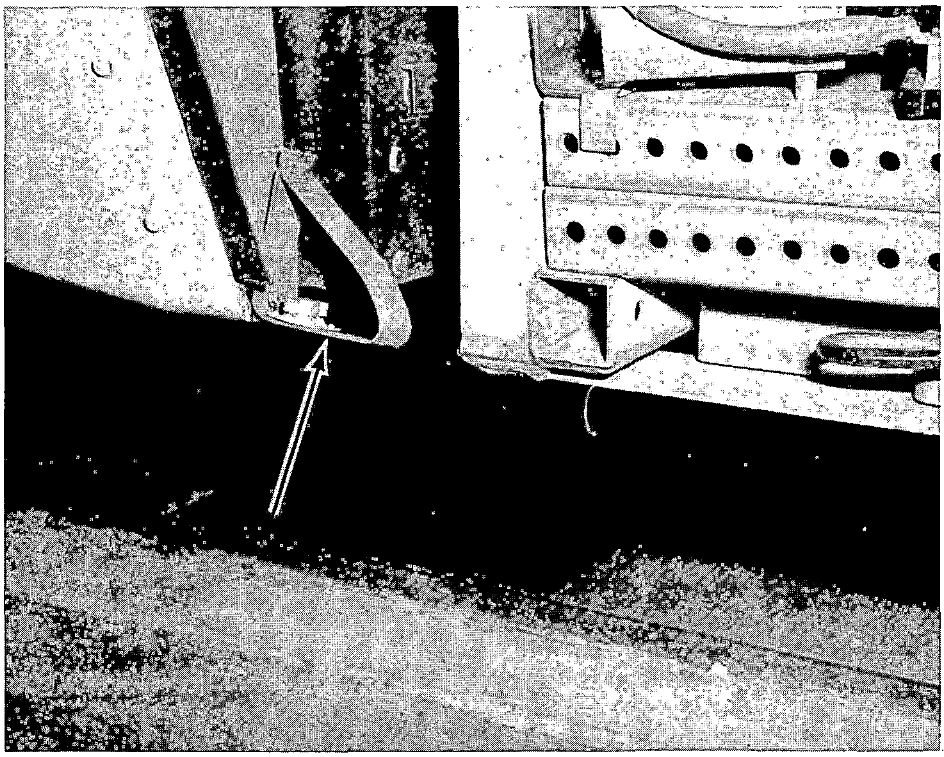


Figure 2–13. Battery Compartment Skirt Panel Retainer

TABLE 2–I. FINAL CONFIGURATION CHANGES TO CARBODY OF DOTX-4 AND DOTX-5

Original Part No.	Component	Changed To
2017338-1	Cab destination sign	Removed
AVCO 26-45000-513	Bay 7B belly pan modified for easy access to Siemens breaker	PA115553
Ohio Brass 523846	A-end coupler modified to provide external brake pipe hose connection; also added pneumatic line and valve for manual pneumatic uncoupling	–
–	Added 12v battery-powered red-and-white taillights	–
–	Slotted skirt panel fasteners replaced with wingnut fasteners	AW6T13, AW6T26
26-31068-7 Plate 26-31068-3 Angle	Modified anticlimber plate and angle to provide clearance for collision test	DOTX-5 only
26-31011-76	Bay 13C beam support assembly replaced with clip bracket at each panel end	–

2.2 PROPULSION SYSTEM

2.2.1 System Description

The ACT-1 propulsion system minimizes energy consumption by using two onboard energy storage units (ESU) which allow for recovery of energy during braking operation. The recovered energy is then reused during vehicle acceleration. In addition to providing the temporary energy storage function, the motor-driven flywheel is used to control the traction motor in response to operator commands.

The energy storage unit (ESU) includes an energy storage flywheel, a planetary gearbox, and a motor/generator which is connected to the flywheel through the gearbox. The antidrive end of the flywheel housing drives an alternator. The ESU also drives a turbocompressor for air conditioning and a blower for equipment cooling. Each railcar employs two ESU's and two traction motors.

Propulsion system major components are listed in Table 2-II. Figure 2-14 shows major component location on the railcar.

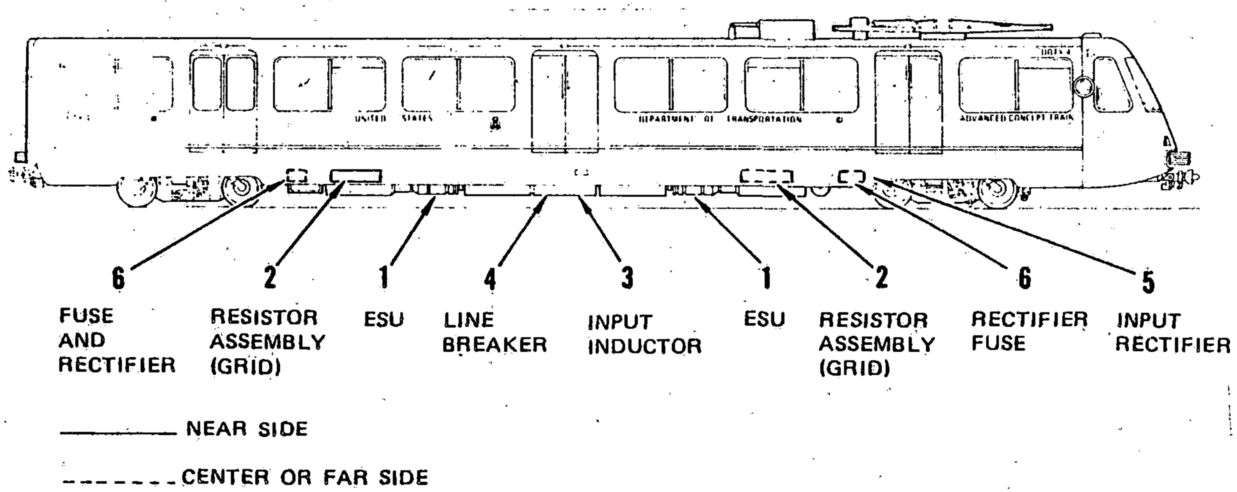


Figure 2–14. Propulsion System Major Component Location

TABLE 2–II. MAJOR COMPONENT INFORMATION

Component	Part No.	Schematic No.
Propulsion Control		2017137
Propulsion Power		2017129
Energy Storage Unit	2017127-1	–
Resistor Assy (Grid)	523830-1	–
Input Inductor	2007362-1	–
Line Breaker	210-0503-9001	–
Rectifier	2017363-1	–
Rectifier Fuse	2017363-2	–
Fuse and Rectifier	2017360-1	–

2.2.2 Operation

The ACT-1 propulsion system has been designed to minimize energy consumption while providing high performance. This is accomplished by using two onboard energy storage units which allow for recovery of energy during braking operation. The recovered energy is then reused during vehicle acceleration. In addition to providing the temporary energy storage function, the motor-driven flywheels are used to control the traction motors in response to operator commands. The power circuit of the ACT-1 propulsion system is shown schematically in Figure 2-15. The principal modes of operation are described in the following paragraphs and are shown schematically in Figure 2-16.

2.2.2.1 Startup Mode (View a, Figure 2-16)

Initial startup of the flywheels prior to placing the railcar in service is accomplished by a single-stage resistive starter circuit which limits inrush current of approximately 400 amps per flywheel. During the intial startup, the separately excited field current is supplied from the high-voltage source and is limited by a series resistor (FR). At approximately 55-percent speed, the auxiliary alternators become operational and provide power to current-regulated, phase-delay-rectifier field supplies. With the electronic controls operational, the startup grid resistors (GR) are shorted by contactors (FMS) to create the idle mode circuit in View b, Figure 2-16. In the idle mode, the flywheel motors are connected across the input line and are regulated to 70-percent speed, which is the nominal minimum operating speed.

2.2.2.2 Parallel Mode Acceleration

During normal driving operation, the flywheels are speed-regulated to a reference schedule that maintains at least 85-percent speed when the railcars are stopped. Upon receipt of a driving command, the flywheel armature voltages are raised above the input supply which reverse-biases the input rectifiers (IR) and reduces line current to zero. At this time, line switch (LS) is

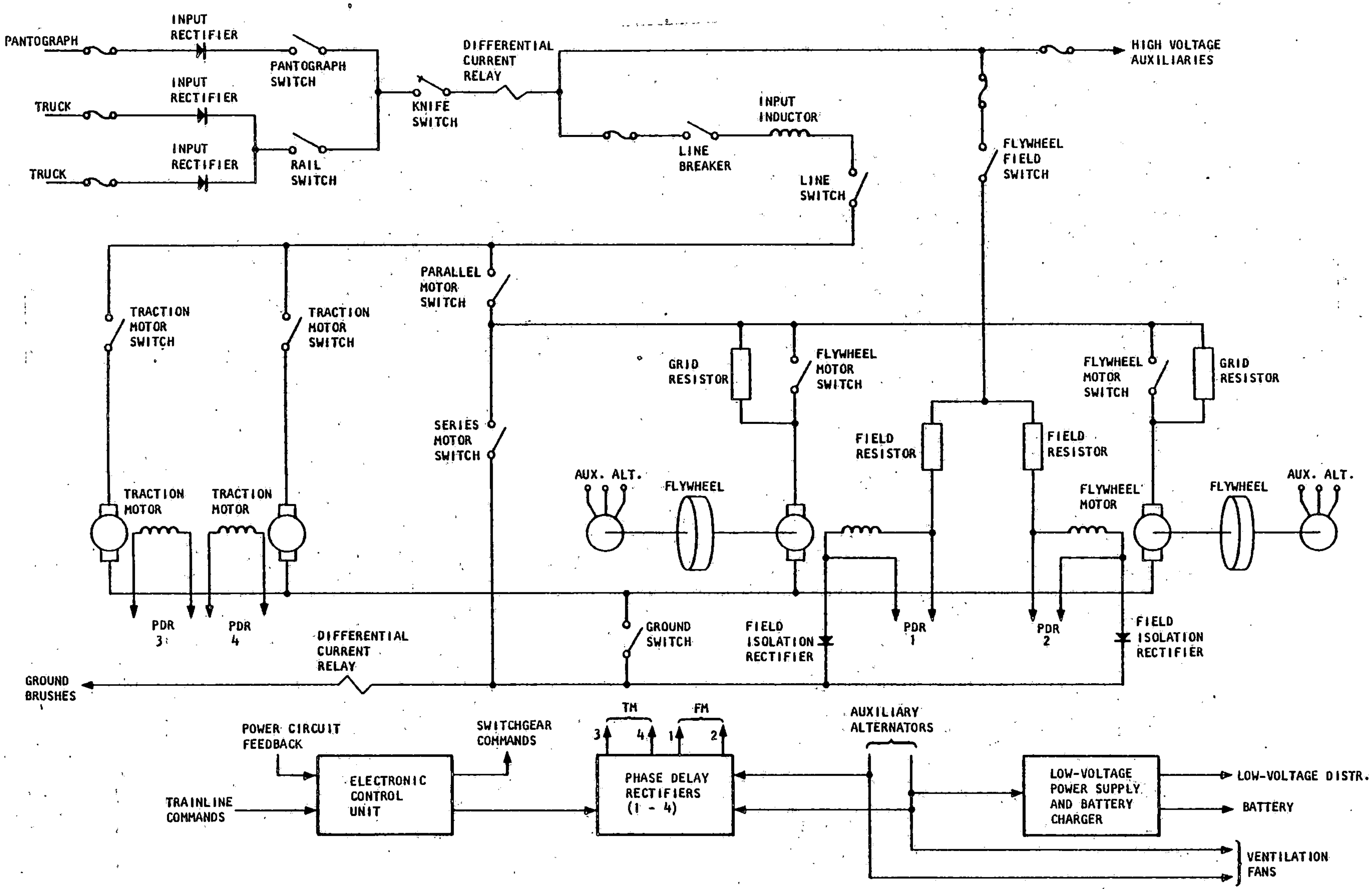


Figure 2–15. Propulsion System Power Schematic

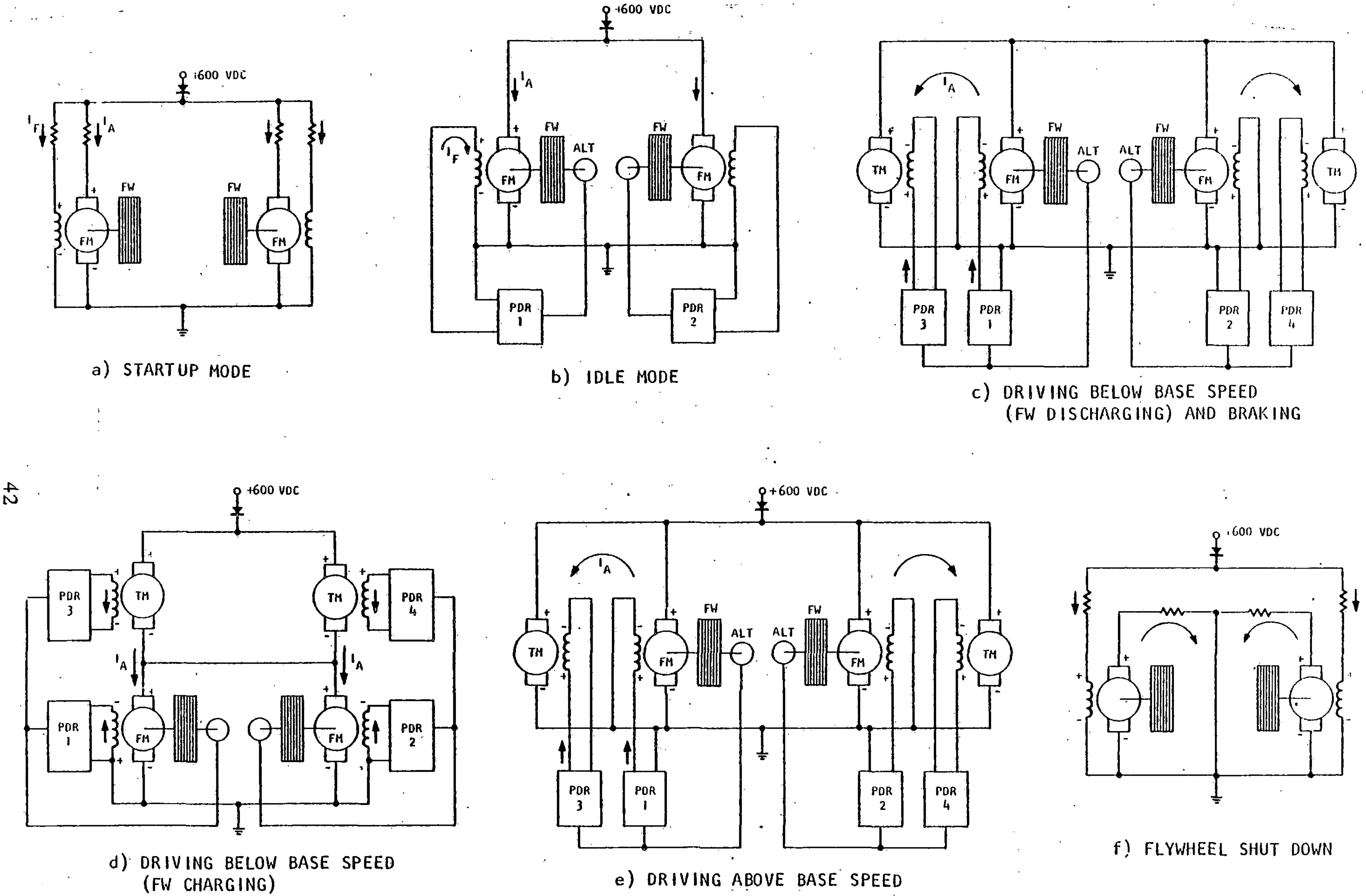


Figure 2–16. Propulsion System Operating Modes

opened and armature voltages are reduced to zero. Closure of the traction motor contactors (TMS) then connects the traction motors in parallel with the flywheel motors to create the parallel motor mode in View c, Figure 2-16. With traction fields at a maximum value, the flywheel fields are used to regulate armature currents to a value proportional to the motorman's command. As the railcar accelerates, armature voltages increase until the input rectifiers are again reverse-biased. Closure of the line switch at this time then connects all motors in parallel across the high-voltage supply as shown in View e, Figure 2-16. After this transition, the traction motor fields are used to regulate traction armature currents and flywheel fields are used to regulate flywheel speed in proportion to the reference schedule. If the flywheel speed remains above the schedule, motor bus voltage is maintained slightly above the supply to prevent the flow of supply current into the vehicle. If flywheel speed drops below the schedule, a closed-loop current regulator controls supply current in proportion to flywheel speed error by adjusting motor bus voltage. In this manner, flywheel energy is given first priority for propelling the railcar and the high-peak currents required for railcar acceleration are taken from the flywheel rather than the high-voltage supply.

2.2.2.3 Braking Mode (View c, Figure 2-16)

When braking command is received, transition to braking is accomplished by merely raising the flywheel motor field to reverse armature current flow. The controls are configured to provide the required jerk limit during this transition.

2.2.2.4 Series Mode

Since the flywheels have only a limited amount of energy available, the parallel mode described above cannot be sustained indefinitely. Therefore, to provide the vehicle capability of continuous operation below base speed, the controls can reconfigure the power circuit to operate the traction motors in series with the flywheel motors as shown in View d, Figure 2-16. During this mode, the flywheel motor is used to supply the difference voltage between the traction motors and the supply. Transition to this mode is initiated as the flywheel speed approaches the minimum value of 70 percent. During this mode, armature current is used to both drive the railcar and to recharge or maintain flywheel speed, depending on operator command level.

2.2.2.5 Shutdown Mode (View f, Figure 2-16)

To provide a method for rapid discharge of flywheel energy either for car layup or due to activation of a fault sensor, the circuit can be reconfigured to dissipate flywheel energy in the startup resistor grids.

2.2.3 Energy Storage Unit (ESU)

There are two energy storage units installed in each ACT vehicle delivered to the Transportation Test Center. They are configured as part no. 2017127-1. During vehicle testing, modifications were made to make the vehicles operational and refine energy-saving performance.

2.2.3.1 ESU Modifications

Flywheel Oil Contamination – Flywheel oil became contaminated with cast-iron-filing particles which caused ESU shutdown. The ESU was removed and it was determined that the resilient flywheel-bearing mount was rotating in its mount, causing the iron particles. The bearing was staked in this unit but this redesign should be incorporated in the remaining ESU's when overhaul is scheduled.

Ringfeder Coupling – The ringfeder coupling which connects the flywheel motor to gearbox slipped circumferentially and axially on its shaft. The motor shaft had previously been machined, flame-spray buildup, and then machined to correct outside diameter. The flame-sprayed metal deposit could not withstand the ringfeder clamping force. It became brittle and eroded under clamping force. This unit was repaired and returned to service. However, any new or overhauled motors should have the shafts ground to virgin metal and smaller diameter ringfeder used.

Low Flywheel Vacuum – The ESU's experienced high pressure in the flywheel cavity. The design vacuum was 25 inches Hg and the automatic shutdown switches were set to 20 inches Hg. The actual pressure was measured to be 18 to 20 inches Hg at 5,000-foot altitude. When G/A could provide no explanation, new switches with a setting of 15 inches Hg were installed which resolved this problem. The higher pressure will increase drag and lower the flywheel efficiency by a small amount.

Oil Seepage Into Flywheel Cavity – The DOTX-5 B-end ESU developed oil leakage into the flywheel cavity. The leakage was attributed to seal wear between the accessory gearbox and the flywheel. The flywheel case was monitored to assess the temperature rise caused by increased flywheel drag and found to be within safe limits.

Alternator Drive – The ESU-driven alternator failed and exhibited a shorted stator. It was replaced with a spare which subsequently failed. When the alternators were disassembled, there was evidence of severe rubbing between the rotor and the stator. An undetermined amount of metal particles was introduced into the flywheel oil system which caused extensive damage to oil pump and filters.

Upon disassembly of the ESU alternator drive shaft assembly, it was found that the bearing nearest the alternator had race damage caused by an out-of-balance condition. This is shown in Figure 2-17. The wear is 0.005 inch deep at the center of the wear spot. This undoubtedly permitted the alternator shaft radial excursion of 0.012 inch under heavy load or misalignment. The bearing at the other end of the alternator drive shaft showed no damage. Absolute certainty of the alternator failure cause is not possible.

Turbocompressor Driven Gear – During operation the turbocompressor drive gear was badly damaged, breaking in several pieces on two separate occasions. The first incident was attributed to poor assembly techniques; the second incident was traced to fatigue fracture of the gear,

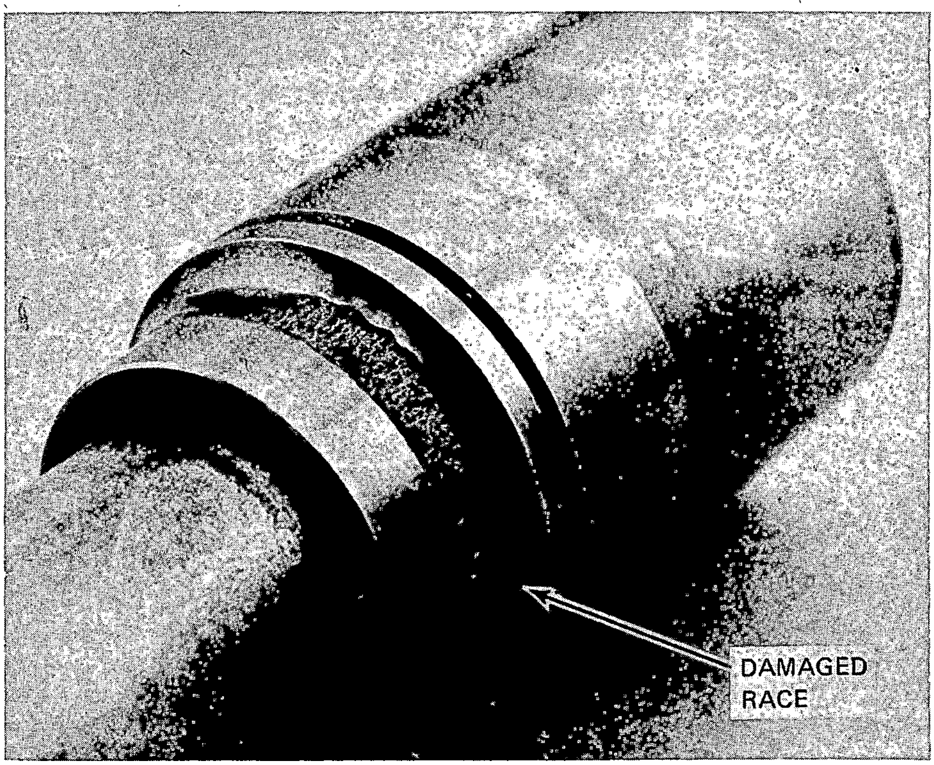


Figure 2–17. Alternator Drive Shaft

which had a porous coating which resulted in a high stress concentration. The units were repaired and made available for installation.

Speed Sensor Gear Drive – The ESU speed sensor gear is driven by a nonmetallic self-lubricating gear. During testing, the nonmetallic gear developed rapid wear of gear teeth and uneven wear patterns.

The gear was redesigned to incorporate a wider tooth and stronger and higher lubricity material. All drive gears were replaced, correcting the problem.

Turbocooler Solenoid Valve – During simulated revenue service testing, the turbocooler solenoid valve developed leakage at the fitting between the oil line fitting and the solenoid housing. In each case, the unit was replaced.

2.2.4 Flywheel and Traction Motors

The flywheel and traction motors are basically identical units which are designated as part no. 2000786-1, Revision A, and 2000784-1, Revision D, respectively. The operational history is as follows:

Vehicle	Unit	Serial No.	Date Installed	Total Hours/Mileage
DOTX-4	A End	FM65-D1	Del	516 hours
DOTX-4	B End	FM36-D5	Del	358.4 hours
		FM36-D3	8-11-78	3.7 hours
		FM65-D3	9-14-78	153.9 hours
		FM65-D3	11-16-78	
DOTX-4	A End	TM96-D1	Del	9,503 miles
		NA	10-23-78	456 miles
DOTX-4	B End	TM105-05	Del	9,959 miles
DOTX-5	A End	FM76-D5	Del	699 hours
DOTX-5	B End	FM36-D3	Del	94.1 hours
		FM65-D2	2-6-78	33.1 hours
		FM105-D4	3-20-78	571.8 hours
DOTX-5	A End	TM65-D3	Del	6,506 miles
		TM96-D1	10-13-78	7,069 miles
DOTX-5	B End	TM65-D2	Del	13,575 miles
High-Time Traction Motor		96-D1		16,572 miles
High-Time Flywheel Motor		76-D5		699 hours

During vehicle testing, the motors experienced many flashovers, overtemperatures, and commutators out of round, reflecting their inability to meet the specification requirements. A summary of operating experience and motor changes is presented below:

2.2.4.1 Motor Brushes

The major motor problem was poor commutation caused by improper brushes. Initial brushes were part no. E68579. The adhesive securing the copper pigtail leads to the carbon brush elements softened at the motor operating temperatures. The pigtails would come loose in the motor cavity, causing flashovers. New brushes incorporating improved adhesive, chamfered edges, and a spring-mounting plate were installed. However, the spring-mounting plate was not securely bonded to the brush wafer elements so that the wafers were not uniformly compressed against the commutator. As a result, the wafers overheated, chipped, and eventually caused flashovers.

The brushes exhibited streamers and hot spots, which were a major cause of commutator flashover and commutator overheating, resulting in commutator bars lifting, thereby aggravating brush wear, slipping, and disintegration. New brushes identified as N4, consisting of a softer material, were installed which virtually eliminated motor flashover problems. A softer brush material was used in the SOAC and WMATA traction motors at the high altitude of the Transportation Test Center. The brush wear rate is considerably higher but is acceptable for a test program.

2.2.4.2 Traction Motor Overtemperature

The traction motors experienced frequent overtemperatures when operated at the AW1 specified duty cycle and under reduced duty cycle at AW2 and AW3. The cooling airflow was increased to the motor but the motor is basically underdesigned. A new motor with higher continuous current capability would be required to meet the power demands of the design specification revenue service profile at weights up to AW3.

The commutator overtemperature coupled with 80-mph operation resulted in lifting commutator bars. As a result the commutators had to be reground on a frequent basis. Incorporation of new brushes, limiting vehicle speed to 70 mph, and reducing the motor armature rms current virtually solved the commutator out-of-round problem.

2.2.4.3 Flywheel and Traction Motor Flashovers

The flywheel and traction motors experienced numerous flashovers. The initial cause of these flashovers was incorrect electronic control and relay logic which simultaneously closed the line, parallel, and series mode switches, thereby shorting the armatures of all four motors at high speed and current. Redesign of interlocking line, parallel, and series mode relay logic eliminated this problem. The major cause of motor flashover was the poor brush performance discussed previously.

A summary of the changes incorporated in the ESU is shown in Table 2-III.

TABLE 2–III. ESU CONFIGURATION: MODIFICATIONS INCORPORATED IN DOTX-4 AND DOTX-5

Original Part No.	Component	Final Part No.
–	Low-vacuum switch – Setting increased from 20 inches Hg to 15 inches Hg	–
573630-5	ESU – Latest configuration	573630-5
Assy 573031-5		Assy 573031-5
573022-1	Bearing support was modified by installation of hardened steel sleeve.	573249-1
573399	Resilient mount was silver-plated to reduce probability of fretting corrosion.	573379-1
–	Antirotation pin was added between seal holder and resilient mount to prevent mount rotation.	–
–	W-00 lockwashers replaced with plain soft steel washers	–
–	ESU speed sensor drive gear	–
–	Oil filters changed from 10 micron to 25 micron	–
–	Motor arc bolts	–
–	FM and TM brushes	–

2.2.4.4 Miscellaneous Propulsion Components

The input inductor, rectifier, and fuse and the grid resistor assembly are identical to the configuration delivered to the test center.

The line breaker current setting was adjusted to increase the interrupt current setting from 1,500 amps to 2,200 amps.

2.2.4.5 Electronic Control Unit (ECU)

The electronic control unit performs all the sensing, controlling, and protecting functions required for the operation of the propulsion system and vehicle. A description of this unit is provided in AiResearch document 77-13741, Revision C, dated 15 March 1977. The configuration delivered to the Transportation Test Center is identified by part no. 2017077-1. The functions performed by the ECU are summarized in Table 2-IV.

Modifications were made to the electronic control units and relay logics to adjust performance to meet specification requirements and to correct design deficiencies. These modifications have been recorded by annotating drawings, prints, and logic diagrams which remain with the ACT vehicles. A summary of the final modification is shown in Table 2-V.

TABLE 2–IV. ELECTRONIC CONTROL UNIT FUNCTIONS

Card	Function
J101	Generates drive and brake signals from trainlines and controls the flywheel field switch (FFS)
J102	Controls traction motor and flywheel motor armature current balance
J103	Controls traction motor field current
	Switches voltage feedback signal from flywheel motor voltage in parallel mode to traction motor voltage in series mode
	Applies friction brakes to prevent rollback until sufficient tractive effort is achieved
J104	Fault monitor for ±15-volt power supply
J105	Monitors flywheel operation and generates shutdown signal when:
	a. Flywheel A and B have quick shutdown
	b. Flywheel senses a quick shutdown
	c. Auxiliary generator fails
	d. P signal opens
	e. Either flywheel overspeeds
	f. A flywheel exceeds temperature limit
	g. Flywheel armature current exceeds 1,500 amps
	h. Flywheel armature voltage exceeds 1,300 volts
	i. Third rail goes negative
	j. Traction motor has quick shutdown
J106	Generates an appropriate quick shutdown signal in event of loss of overscale of traction motor parameters
J108 J201	Provides voltage level transformation from battery to ECU power supply voltage
J110	Monitors various fault detectors and indicates first event that causes system shutdown
J111 J112	Inserts a digital buffer between ECU logic and systems monitor
J113 J114	Adds a stage of buffering and gain change to drive the analog meter to monitor various propulsion system parameters
J202	Generates digital information from analog signals primarily for logic decisions

TABLE 2–IV – Continued

Card	Function
J203, J204, J205	Generates digital information based on comparisons of analog voltage levels with preset voltages to perform the logic to control modes and contactors
J206	Performs logic to change the two parallel and series drive configurations and self-checks correct contactor arrangement
J207	Performs logic to configure propulsion system to obtain traction motor current
J208	Controls voltage commands to allow transition between different modes of operation
J209	Generates digital signals that control the action of the traction and fly-wheel motor field phase delay rectifiers
J210	Generates drive signals to reversing contactors on the field phase delay rectifiers of the traction and flywheel motors including self-check of correct contactor configuration
J211	Controls the parallel mode switch and series mode switch contactors
J212	Controls the flywheel mode switch and traction mode switch contactors
J213	Contains logic to operate the line breakers contactor
J214	Contains logic to operate the ground switch contactor
J302, J304	Provides flywheel overspeed protection
J303	Monitors all flywheel speed sensors and detects all overspeeds
J305	Monitors flywheel parameters and sets latching relays for quick shutdown: a. Vacuum b. Oil pressure c. Oil temperature
J306, J307, J308, J309, J310	Performs necessary signals to interface between the analog and digital systems
J311, J312	Performs necessary analog voltage and current scaling
J405	Performs slip-slide functions including detection, operation, and release after 3 seconds

TABLE 2–IV – Continued

Card	Function
J406	Generates the necessary signals to balance the traction motor currents by changing the flux in the traction motor; produces the third-rail current command through the flywheel speed regulator
J408	Generates the system voltage commands required to change modes of operation; flywheel speed schedule based on traction motor speed is also generated
J409	Generates the signals needed to keep the flywheel armature currents and speeds in balance
J411	Produces the traction motor armature current limit in drive and brake
J412	Generates the traction motor armature current commands when slip and slide conditions prevail in track
J413	Produces traction motor current command based on master controller position and weight compensation
J501 J507 J508	Generates electropneumatic valve current to command correct amount of friction brakes
J502	Converts traction motor speeds to analog and selects highest for control purposes
J503	Detects spins and slides of each truck when acceleration or deceleration rates are in excess of 6 mphps
J505	Interfaces slide relays with brakes
J509 J510	Adjusts the total friction brake command when a slide occurs during brake; the circuit is designed to find the adhesion limit of the rail based upon slide information
J511	Generates a voltage proportional to pressure out of air bag expansion system (weight); also generates traction motor armature current limits based on weight and adjusts current command by P signal
J512	Generates friction brake command based upon master controller position adjusted for varying weight
J513	Performs propulsion and friction brake blending

TABLE 2–V. ECU MODIFICATIONS

Part Number		Change
2014238	J203	Third-rail voltage increased high limit to 775v; lowered low limit to 425v
–	J209	Vent fan schedule: off at 67% and on 68.1% ESU speed
–	J511	Reduce traction motor armature current to 700 amps in braking
–	A-12	Clamped P signal to 10 vdc maximum
2014282	J410	Eliminates random shutdowns of propulsion system caused by high-frequency noise
2014240	J105	Delayed QSD signal from battery charger to prevent transients from shutting down vehicle
–	Main Frame	Added flywheel motor overcurrent indicator to monitor panel
2014204	J512	Adjusted brake cylinder pressures weight schedule to AW1 = 57 psi and AW3 = 73 psi
2014254	J508	Adjusted electric braking blending to meet specification requirements
2014234	J413	Adjusted electric braking weight schedule to AW1 = 690 amps, AW3 = 900 amps
2014260	J209	Filtered auxiliary generator fail signal to eliminate spurious auxiliary generator trips
2014208	J305	Add 1.5-second time delay to flywheel shutdown circuit to eliminate spurious low oil pressure
2014278	J409	Improve flywheel speed balance
–	A10	Bypassed ESU low-oil-pressure shutdown
2014252	J501 J507	Adjusted brake release current to 268 ma on both trucks
2014260(6/13)	J209	Extensive modifications to adjust following performance
2014254(6/5)	J508	a. Acceleration
2014218(6/5)	J510	b. Electric, blended, friction braking
2014252(6/5)	J501 J507	c. Speed regulation d. Spin-slide
2014290(6/5) (mod -27)	J505	e. Weight adjustment f. Energy consumption g. Fault protection logic

2.3 TRAIN CONTROLS

The functions of the train control system are to integrate major vehicle subsystems, provide commands, monitor system status, regulate vehicle speed and braking, and prevent undesired vehicle motion. The primary train control systems used on the ACT-1 vehicles consist of the motorman's control panel, the hostler control panel, and the speed control unit.

The motorman's control panel provides the controls, switches, and indicators required for complete operation and control of the ACT-1 vehicles. Control panel components are identified in Figure 2-18. Table 2-VI lists the panel markings, initial settings, description, and function of each component.

The hostler control panel, located in the B end of each vehicle, provides limited train control from the B end of the vehicle. It is used primarily for coupling and uncoupling the two ACT-1 vehicles. Hostler control panel components are identified in Figure 2-19. Panel markings, description, and component function are listed in Table 2-VII.

The speed control unit provides overspeed protection, automatic speed regulation, and tractive effort commands to the trainlines from the lead cab of a two-car consist. The unit consists mainly of printed wiring assemblies and relays which function during automatic modes of vehicle operation. There are no controls or indicators on the front panel of this unit.

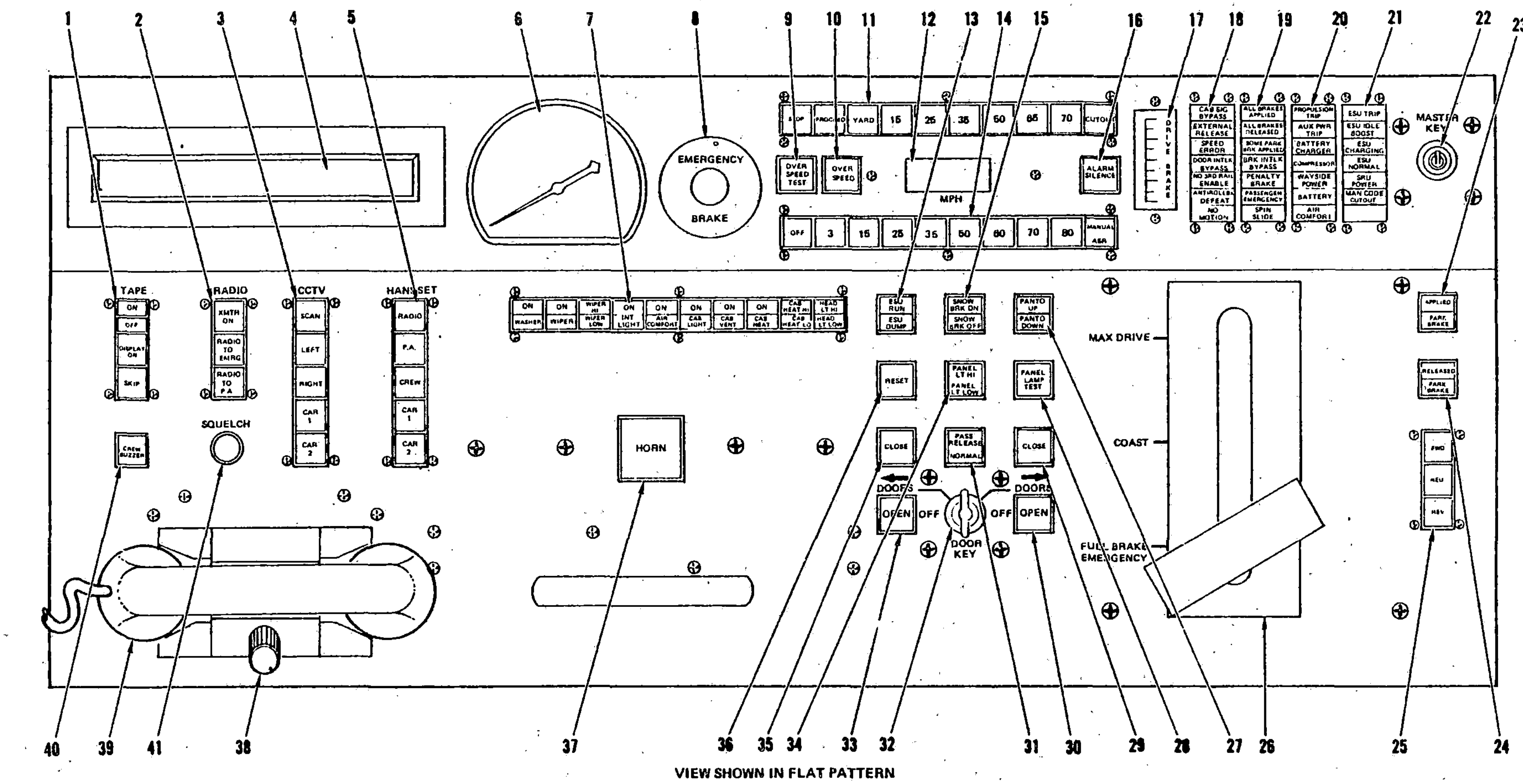


Figure 2–18. Motorman's Control Panel

TABLE 2–VI. MOTORMAN'S CONTROL PANEL CONTROLS AND INDICATORS

Index No. (see Figure 2-18)	Legend/Panel Marking	Initial Setting	Description	Function
1	TAPE	–	Switch assembly	Controls mode of station announce system as indicated by detail switch legends as follows:
	ON/OFF	ON	Switch/indicator	Activates tape system; ON indicates automatic operation, OFF indicates standby mode in which automatic advancement of message is inhibited. Split legend switch cap illuminated to indicate status.
	DISPLAY ON	–	Switch/indicator	Illuminates passenger station displays to coincide with motormans display, if it is illuminated. Switch cap illuminated to indicate passenger displays are illuminated.
	SKIP	–	Switch/indicator	Advances tape one station beyond next scheduled station. This resets DISPLAY ON indicator to OFF, extinguishing and muting the passenger display stations. The SKIP indicator will light during a skip cycle, extinguishing after the skip cycle in progress is completed. At the end of each skip cycle a new cycle may be initiated if desired. When the desired scheduled station stop appears on the motorman's display, it may be indicated on passenger displays by depressing DISPLAY ON switch. DISPLAY ON will activate automatically when doors open at next stop.
2	RADIO	–	Switch assembly	Controls and indicates status of radio system as indicated by detail light and switch legends as follows:

TABLE 2–VI – Continued

Index No. (see Figure 2-18)	Legend/Panel Marking	Initial Setting	Description	Function
	XMTR ON	–	Indicator	Indicates radio is in transmitting mode when illuminated.
	RADIO TO EMRG	OFF	Switch/indicator	Switches radio transmitter to emergency frequency. Active when illuminated.
	RADIO TO P.A.	OFF	Switch/indicator	Switches radio receiver output to public address system. Active when illuminated.
3	CCTV	–	Switch assembly	Controls status of closed circuit television as indicated by detail switch legends and referenced to direction of travel as follows:
	SCAN	ON	Switch/indicator	Commands CCTV system to select internal cameras from first to last repetitively. Active when illuminated.
	LEFT	–	Switch/indicator	Commands left exterior camera operation. Active when illuminated.
	RIGHT	–	Switch/indicator	Commands right exterior camera operation. Active when illuminated.
	CAR 1	–	Switch/indicator	Commands lead car interior camera operation. Active when illuminated.
4	–	–	Station announce displays	Displays station to be announced.
5	HANDSET	–	Switch assembly	Controls selection of circuit to be connected with handset as indicated by detail switch legends as follows:

TABLE 2–VI – Continued

Index No. (see Figure 2-18)	Legend/Panel Marking	Setting	Description	Function
	RADIO	ON	Switch/indicator	Connects handset receiver or microphone when hand-set talk bar is depressed to radio control with central control.
	P.A.	–	Switch/indicator	Connects handset to public address system when talk bar is depressed.
	CREW	–	Switch/indicator	Initiates call to other cab or answers call from any crew station.
	CAR 1	–	Switch/indicator	Connects handset to lead railcar passenger intercom.
	CAR 2	–	Switch/indicator	Connects handset to car 2 passenger intercom.
6	–	–	Air gage	Indicates air pressure in main reservoir as indicated by white pointer and in brake cylinders as indicated by red pointer.
7	–	–	Switch assembly	Controls selection of mode applied to the following accessories or systems as indicated by detail switch legends.
	ON WASHER	–	Switch/indicator	Turns windshield washer ON/OFF.
	ON WIPER	–	Switch/indicator	Turns windshield wiper ON/OFF.
	WIPER HI WIPER LOW	–	Switch/indicator	Permits selection of high or low windshield wiper speed.
	ON INT LIGHT	–	Switch/indicator	Turns interior lights ON/OFF in both cars of a two-car consist.
	ON AIR COMFORT	–	Switch/indicator	Turns air-conditioning recirculation fan and comfort control unit ON/OFF on both cars.

TABLE 2–VI – Continued

Index No. (see Figure 2-18)	Legend/Panel Marking	Setting	Description	Function
	ON CAB LIGHT	–	Switch/indicator	Turns cab lights ON/OFF.
	ON CAB VENT	–	Switch/indicator	Turns cab vent fan ON/OFF.
	ON CAB HEAT	–	Switch/indicator	Turns cab heater ON/OFF.
	CAB HEAT HI CAB HEAT LO	–	Switch/indicator	Permits selection of high or low cab heat
	HEAD LT HI HEAD LT LOW	–	Switch/indicator	Permits selection of high or low beam for headlights. NOTE Headlights are turned on by selecting the FWD direction on item 25 and master key activation.
8	EMERGENCY BRAKE	–	Switch	Controls application of EMERGENCY brake without slip/slide protection. When initiated, brake cannot be released until railcar has stopped and master controller is moved to FULL BRAKE.
9	OVERSPEED TEST	–	Switch/indicator	Establishes 5-mph command to OVERSPEED detector.
10	OVERSPEED	–	Indicator light	Indicates speed in excess of that allowed by cab signal equipment.
11	–	–	Indicator light assembly (cab signal aspect)	If cab signal equipment is functional, this displays status of signal aspect (speed limit) received from wayside station.
12	MPH	–	Speedometer	Indicates railcar speed.

TABLE 2–VI – Continued

Index No. (see Figure 2-18)	Legend/Panel Marking	Setting	Description	Function
13	ESU RUN ESU DUMP	–	Switch/indicator	Energizes trainline to enable startup and operation of energy storage units. Activation when ESU RUN is illuminated will cause immediate shutdown of all energy storage units.
14	–	–	Switch/indicator assembly	Permits selection of speed limit for manual control mode. One of the speeds from 3 to 80 mph (as indicated on button) or OFF may be selected. Note: MANUAL/ASR has no function.
15	SNOW BRK ON SNOW BRK OFF	–	Switch/indicator	Controls selection of ON or OFF mode for snow brake.
16	ALARM SILENCE	–	Switch/indicator	Permits cancellation of overspeed audio alarm.
17	DRIVE/BRAKE	–	Meter (P signal)	Display tractive effort and brake command signal.
18	–	–	Indicator light assembly	When lit, placarded light assembly segments as detailed below indicate the following:
	CAB SIG BYPASS	–	Indicator	Indicates that cab signal bypass switch is in BYPASS position.
	EXTERNAL RELEASE	–	Indicator	Indicates that radio release contact or external release switch contact is closed.
	SPEED ERROR	–	Indicator	Indicates that tachometers do not agree, or speed is in excess of 83 mph.
	DOOR INTLK BYPASS	–	Indicator	Indicates door bypass switch is ON.

TABLE 2–VI – Continued

Index No. (see Figure 2-18)	Legend/Panel Marking	Setting	Description	Function
	NO 3RD RAIL ENABLE	–	Indicator	Indicates no 3rd rail enable switch is ON.
	ANTIROLL BK DEFEAT	–	Indicator	Indicates antirollback defeat switch is ON.
	NO MOTION	–	Indicator	Indicates no motion relay is energized.
19	–	–	Indicator light assembly	When lit, placarded light assembly segments detailed below indicate as follows:
	ALL BRAKES APPLIED	–	Indicator	Indicates that all friction brakes are applied.
	ALL BRAKES RELEASED	–	Indicator	Indicates that all friction brakes are released.
	SOME PARK BRK APPLIED	–	Indicator	Indicates that some parking brake on either car is not OFF.
	BRK INTLK BYPASS	–	Indicator	Indicates that brake interlock bypass switch is in BYPASS position.
	PENALTY BRAKE	–	Indicator	Indicates that the ATO emergency is relay deenergized.
	PASSENGER EMERGENCY	–	Indicator	Indicates that some passenger emergency switch has been activated.
	SPIN SLIDE	–	Indicator	Indicates loss of wheel adhesion on either car.
20	–	–	Indicator light assembly	When lit, placarded light assembly segments detailed below indicate as follows:
	PROPULSION TRIP	–	Indicator	Indicates that some propulsion system on railcar has tripped.

TABLE 2–VI – Continued

Index No. (see Figure 2-18)	Legend/Panel Marking	Setting	Description	Function
	AUX PWR TRIP	–	Indicator	Indicates that some auxiliary power system on railcar has tripped.
	BATTERY CHARGER	–	Indicator	Indicates that some battery charger on railcar has failed.
	COMPRESSOR	–	Indicator	Indicates that a compressor on railcar has failed.
	WAYSIDE POWER	–	Indicator	Indicates presence of wayside voltage.
	BATTERY	–	Indicator	Indicates that a battery is below 24 volts on either car.
	AIR COMFORT	–	Indicator	Indicates that some air comfort system on railcar has failed.
21	–	–	Indicator light assembly	When lit, placarded light assembly segments detailed below indicate as follows:
	ESU TRIP	–	Indicator	Indicates that some energy storage unit on railcar has shut down.
	ESU IDLE BOOST	–	Indicator	Indicates that idle speed of energy storage units has been raised to 85% from normal 70%.
	ESU CHARGING	–	Indicator	Indicates that some energy storage unit on railcar is charging.
	ESU NORMAL	–	Indicator	Indicates that all energy storage units are charged.
	SRU POWER	–	Indicator	Indicates power applied to speed regulation unit has failed.
	MAN CODE CUTOUT	–	Indicator	Indicates manual code cutout switch activated.

TABLE 2–VI – Continued

Index No. (see Figure 2-18)	Legend/Panel Marking	Setting	Description	Function
22	MASTER KEY	–	Switch	Unlocks master controller and established lead railcar.
23	APPLIED PARK BRAKE	–	Switch/indicator	Permits application of parking brakes. Also indicates position when all parking brakes are applied.
24	RELEASED PARK BRAKE	–	Switch/indicator	Permits release of parking brakes. Also indicates when all parking brakes are released.
25	FWD NEU REV	–	Switch/indicator	Permits selection of car direction either forward, neutral, or reverse.
26	MAX DRIVE COAST FULL BRAKE EMERGENCY	–	Master controller	Controls forward and braking mode command signal.
27	PANTO UP PANTO DOWN	–	Switch/indicator	Provides control of positioning pantograph UP or DOWN. Indicator will flash on and off when not in commanded position.
28	PANEL LAMP TEST	–	Switch	Permits check of all lamps on motorman control panel by illuminating all lamps simultaneously.
29	CLOSE	–	Switch/indicator	Closes all doors on right side of railcar and illuminates when all doors are closed.
30	OPEN	–	Switch/indicator	Opens doors on right side of railcar and illuminates to indicated that some door is open on right side of railcar.
31	PASS RELEASE NORMAL	–	Switch/indicator	When in PASS RELEASE position, allows passengers to open doors. Prevents passengers from opening doors when in NORMAL position.

TABLE 2–VI – Continued

Index No. (see Figure 2-18)	Legend/Panel Marking	Setting	Description	Function
32	DOOR KEY	–	Switch	Provides control of door system and selection of left or right side doors.
33	OPEN	–	Switch/indicator	Opens doors on left side of railcar and illuminates to indicate that some door is open on left side of railcar.
34	PANEL LT HI PANEL LT LOW	–	Switch/indicator	Provides control of intensity panel lights. (Master key turns lights on.)
35	CLOSE	–	Switch/indicator	Closes all doors on left side of railcar and illuminates when all doors are closed.
36	RESET	–	Switch/indicator	Used in propulsion system to start up and to reset.
37	HORN	–	Button	Provides control for sounding horn.
38	–	–	Handset control	Adjusts volume of handset receiver.
39	–	–	Handset	Used for public address, radio, and intercom systems. Equipped with push-to-talk switch for public address and radio systems.
40	CREW BUZZER	–	Switch	Activates buzzer to signal crew, and P.A. tone generator.
41	SQUELCH	Quiet	Control	Cancels receiver noise during absence of signal.

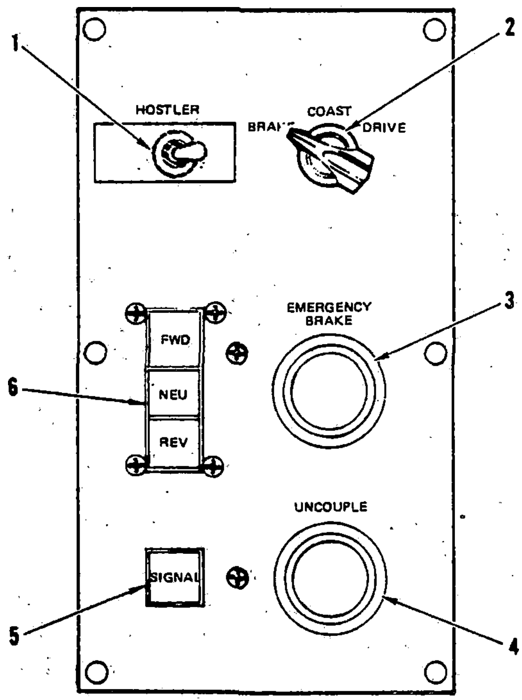


Figure 2–19. Hostler's Control Panel

TABLE 2–VII. HOSTLER'S CONTROL PANEL CONTROLS AND INDICATORS

Index No. (see Figure 2–19)	Legend/ Panel Marking	Description	Function
1	HOSTLER	Switch	Controls power application for hostler panel operation. ON is to left; closing panel access door turns the switch off.
2	BRAKE COAST DRIVE	Switch	Provides selection of tractive/ brake mode of hostler control. Upon release, switch returns to BRAKE position.
3	EMERGENCY BRAKE	Switch	Commands EMMERGENCY brake application when actuated. Railcar must stop before normal control can resume.
4	UNCOUPLE	Switch	Is depressed and held when power uncoupling is to be effected.
5	SIGNAL	Switch	Is depressed to activate crew buzzer on hostler's panel and in motorman's cab.
6	FWD NEU REV	Switch Assembly	Provides control of direction of railcar when under hostler control. When FWD is selected, railcar moves with cab (A end) leading.

2.3.1 Final Configuration

The ACT-1 train control system as delivered to Pueblo is shown in AiResearch drawings 2017104 and 2018476. During the test program, changes were made to improve vehicle operation and performance. These changes are described below and summarized in Table 2-VIII to define the final configuration of the ACT-1 vehicles as delivered to UMTA at the completion of the test program.

2.3.1.1 Cab Signal Pickup Coil

The cab signal pickup coil and support brackets, AiResearch drawings 2017468 and 2017469, were removed and stored in the SMB at the Transportation Test Center. The vehicles were delivered to Pueblo without cab signalling equipment installed and there was no cab signal testing planned; therefore, it was decided to remove and store the components. In addition, it made truck maintenance easier to perform.

2.3.1.2 Speed Regulation Unit

The speed regulation unit (SRU) printed circuit board, AiResearch drawing 2017591, was modified to defeat the 30-mph speed limit in reverse. This was necessary during single-car testing to allow 0-80-mph test runs in both directions. An additional modification was made to the SRU board to adjust the overspeed correction circuits. Rg was changed to 22.6k and R_{10} was changed to 178k and a 1-μfd capacitor was added between the input of op-amp, U3B, and ground.

These changes applied the vehicle penalty brake at a speed of 83.5 mph, slowing the car to 75.5 mph where it released. The added capacitor functions as a noise rejection filter to preclude random application of the penalty brake.

2.3.1.3 P Signal Conditioner

The P signal conditioner printed circuit board, AiResearch drawing 2017593-1, was modified to allow greater resolution in the adjustment of the P handle coast position. R_{33} was changed to a 10k potentiometer and the P handle coast position output was adjusted to 5.0 ± 0.005 vdc.

An additional modification was made to the P signal conditioner board to ensure the maximum P signal (maximum drive) did not exceed 100-percent drive. During the test program it was found that the vehicle operator could command a P signal of 110 percent by pushing the master controller handle full forward. The modification consisted of adding a voltage clamp circuit to the output of op-amp U2B. This limited the P handle command to 100 percent.

2.3.1.4 Automatic Speed Regulation

The vehicle operator select automatic speed control, AiResearch drawing 2017591, was modified to calibrate the unit for the proper speeds. The following resistor values were changed:

TABLE 2–VIII. FINAL CONFIGURATION CHANGES TO TRAIN CONTROLS OF DOTX-4 AND DOTX-5

Part No.	Component	Changed to
2017468 2017469	Cab signal pickup coil and support Brackets	Removed and stored.
2017591	Speed reg unit – components changed to adjust overspeed limits	R9 = 22.6kΩ, R10 = 178kΩ, added 1 capacitor
2017591	Speed reg unit – to allow 80 mph runs in reverse	Wiring change to bypass 30-mph speed limit in reverse
2017593-1	P sig conditioner – fixed resistor changed to an adjustable resistor	R33 = 10k potentiometer
2017593-1	P sig conditioner – circuitry added to clamp P sig to 10.0 vdc	Added two resistors to output of U2B
2017591	Resistors changed to calibrate the auto speed control (DOTX-4 only); change already in DOTX-5 at WAF)	R11 = 4.3 Mr, R17 = 24.8 Kr R19 = 20.6 Kr, R21 = 17.4 Kr R22 = 14.7 Kr
2017379-1	Added on/off switch to allow headlights to stay on in reverse	On-off switch connected between TB2-7 and TB2-6
2017104	Hostler control relay (modified per CR 120717)	Hostler control relay contacts parallel dead man relay trainline
2017104	Parking brake interlock control circuitry	Modified to prevent release of B truck service brakes and application of tractive effort

R_{11} to 4.3M, R_{17} to 24.8k, R_{19} to 20.6k, R_{21} to 17.4k, and R_{22} to 14.7k. This change was made on DOTX-4 only because DOTX-5 had arrived at Pueblo with the change already incorporated.

2.3.1.5 Trainline Controls

An on-off switch has been added between TB2-7 and TB2-6 of the accessory control panel to override the trainline circuit which automatically transferred the headlights to the lead cab of a two-car consist. This allowed the headlights to remain on when a single car was being operated in reverse. This was required by the test center during test running on the transit test track.

2.3.1.6 Hostler Control

The hostler control circuitry was modified to allow the vehicles to be driven from the B end without having someone hold the deadman closed at the motorman's P handle. The modification as installed ties the deadman relay in parallel with the hostler control relay so that deadman trainline is complete when the hostler control relay is energized.

2.3.1.7 Parking Brake Interlock

The parking brake control circuitry was modified to prevent the vehicle operator from releasing service brakes on the B truck and commanding tractive effort when the parking brakes are applied.

2.4 TRUCKS

2.4.1 Truck Description

The ACT-1 railcar employs two lightweight monomotor truck assemblies, one at station 191 and the other at station 791. Each truck assembly includes a double-ended electric traction motor, two drive axles, an air-operated disc brake at each wheel, a frame, and a suspension system. The truck assembly is shown in Figure 2-20.

The electric traction motor is rubber-mounted in the center of the truck frame between the two drive axles and permits full articulation. The double-ended motor is connected to identical drive axles with direct-drive couplings; however, because one axle is 180 degrees opposed to the other, one axle drives on the drive side of the gearing while the other axle drives on the coast side.

Each axle employs a modular welded housing with spindle ends and aluminum-centered retreadable wheel/hubs. Each wheel hub is mounted on a spindle with two tapered-roller bearings. The axle drive unit is a single-reduction, hypoid final drive employing a heavy-duty bevel hypoid pinion and ring gear. The ring gear is fastened to a drive flange case which is mounted in the carrier on two tapered-roller bearings. The pinion is straddle-mounted between two

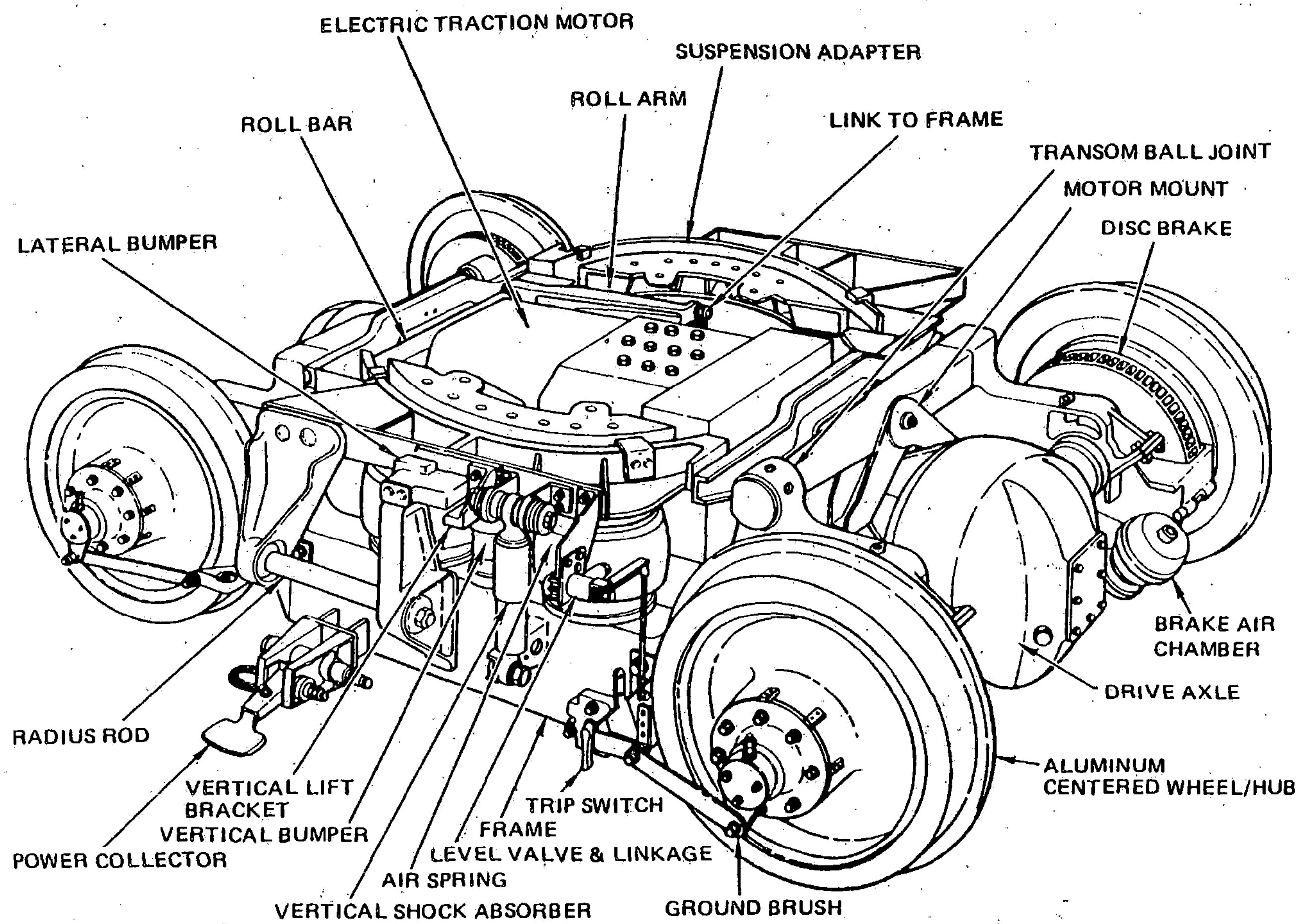


Figure 2–20. Truck Assembly

tapered-roller bearings in front of the pinion teeth which take the forward and reverse thrust and a third, straight-roller-type bearing behind the pinion teeth to carry the radial load. Power is transmitted by the drive pinion, ring gear, and drive flange case directly through half shafts to the wheel ends.

Each wheel of the truck assembly employs a high-thermal-energy-absorbing disc brake system which is an air-operated, wedge-activated, automatic-adjusting unit powered by one standard air chamber. Additionally, each of the four brake assemblies on the front truck has a spring-powered parking brake assembled piggyback over the standard air chamber. These units are air-activated for parking brake release.

The frame of the truck assembly is a low-weight cast/weldment structure which is fully articulated. The air suspension system employs primary and secondary systems which are self-leveling, with the air reservoir being incorporated in the frame structure. Rubber bumpers are located between the frame and suspension to limit travel while internal airspring bumpers eliminate metal-to-metal contact in the event of air loss. The suspension is low-rate-damped with one lateral and two vertical shock absorbers, while the complete unit is rollbar stabilized.

In operation, the suspension adapter transmits lateral and longitudinal forces from the carbody to truck with vertical loads being transmitted directly over four airsprings. The springs permit vertical movement when the vehicle is in operation while leveling valves control operating height and air pressure to compensate for variable passenger loads. The longitudinal forces are transmitted from the carbody to the truck through radius rods located above the axle centerline.

A third-rail power-collector paddle is mounted on each side of each truck. A ground brush assembly is provided on each wheel.

2.4.2 Final Configuration

The ACT-1 trucks as delivered to the Transportation Test Center are defined by drawing 2000531-1 for the A end and drawing 2000531-2 for the B end. The test program at TTC necessitated some truck changes which are described below and summarized in Table 2-IX to define the final truck configuration as delivered to UMTA upon completion of the TTC test program.

2.4.2.1 Rollbar Link

The ACT-1 vehicle test plan required measurement of a truck rollbar torsional moment. To satisfy this requirement an instrumented rollbar link was fabricated as shown in Figure 2-21 and installed on the B-end truck of DTOX-5 in place of Rockwell International part number 2244-C-3X.

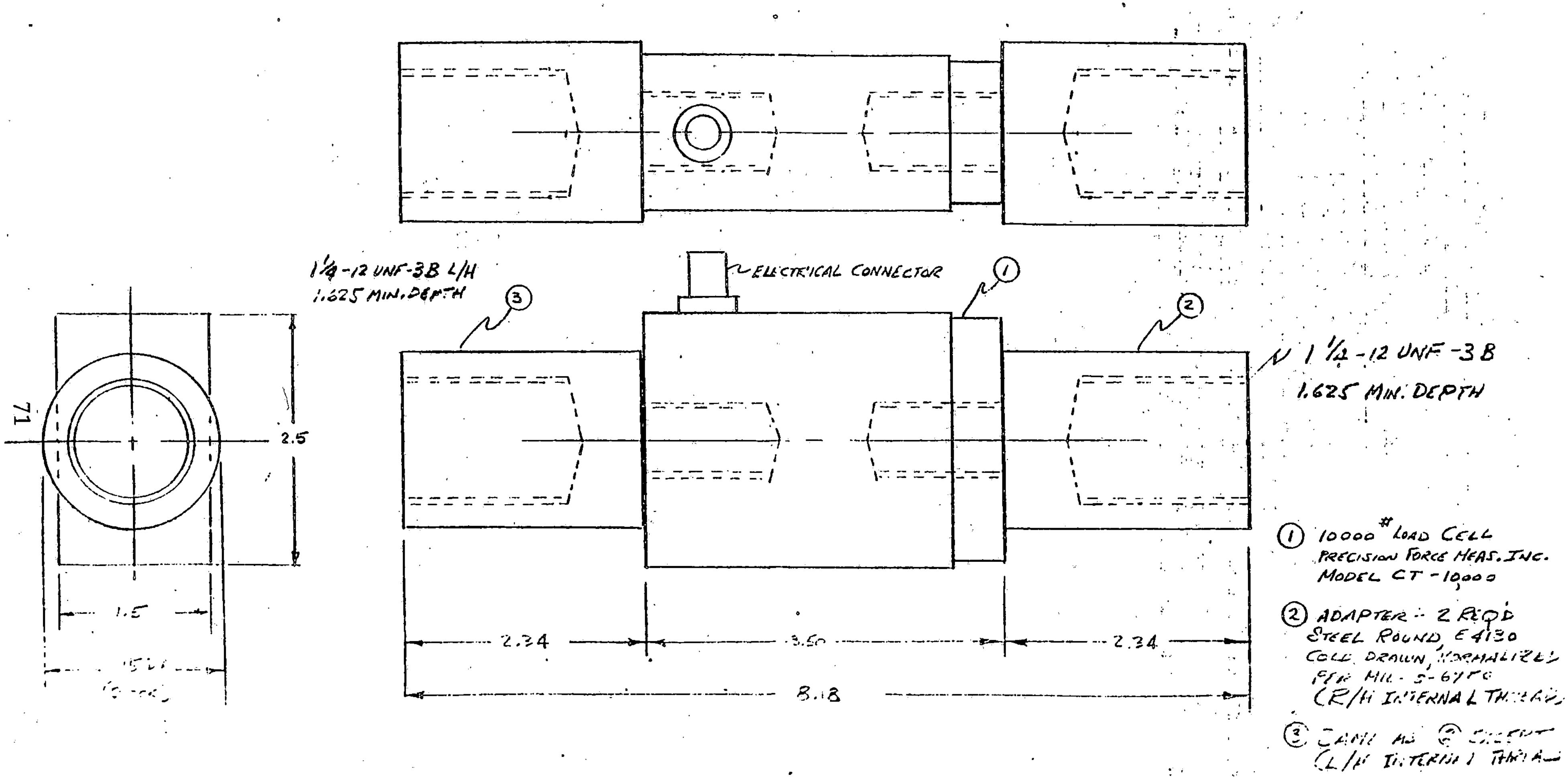


Figure 2–21. Instrumented Truck Rollbar Link

TABLE 2–IX. FINAL CONFIGURATION CHANGES TO TRUCKS OF DOTX-4 AND DOTX-5

Original Part No.	Configuration	Changed to
Rockwell 2244-C-3X	Instrumented rollbar link fabricated by Boeing Vertol replaces original link	Instrumented link
	Lateral stops castings machined to provide adequate wheel clearance	
Rockwell SCD-A4-3280-R-6726X	Cracked lateral damper bracket beefed up with 3/4-inch plate	
2017479-6-13	Pneumatic hose support impacts carbody	Cut corner off bracket
	Axle breathers	Rubber washer replaced with felt washer

2.4.2.2 600-Volt Stinger Adapter

The ACT-1 cars as delivered to TTC did not provide a means of connecting the 600v power source available in the Transit Maintenance Building (TMB) to the cars. To provide this capability, a TTC-supplied 600v female stinger assembly as shown in Figure 2-22 was added to the shunt lug of a truck. The location of this stinger assembly was moved from one truck to the other or from one side to the other as test needs dictated. However, the final configuration as delivered had the assembly installed on the right side of the rear truck on DOTX-4 and on the left side of the rear truck on DOTX-5.

2.4.2.3 Lateral Stops

During preliminary adjustments of DOTX-5 after arriving at TTC, it was noted that the lateral stop casting was rubbing on the wheel flange on the number 1 and number 8 wheels. Approximately a 1-inch by 2-inch triangular section was removed from the lateral stop casting at these two locations to provide adequate clearance. In addition, two 1/4-inch shims were added to the top of each marshmallow assembly to provide additional clearance.

2.4.2.4 Lateral Damper Bracket

After approximately 4,600 miles of operation with DOTX-4, the inboard lateral damper bracket on the A truck was found cracked from a torsional load and the B-truck bracket was completely broken off as shown in Figure 2-23. The bracket is shown in Figure 2-24, which is section E-E from Rockwell International drawing SCD-A4-3280-R-6726X, welded adapter suspension assembly.

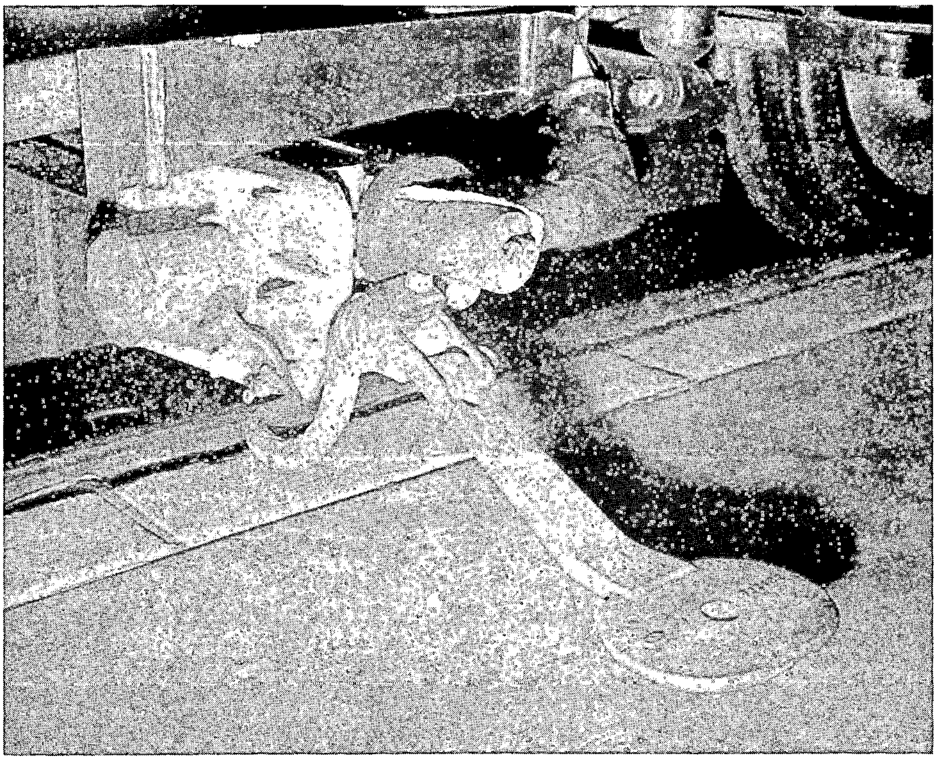


Figure 2–22. 600-Volt Stinger Adapter

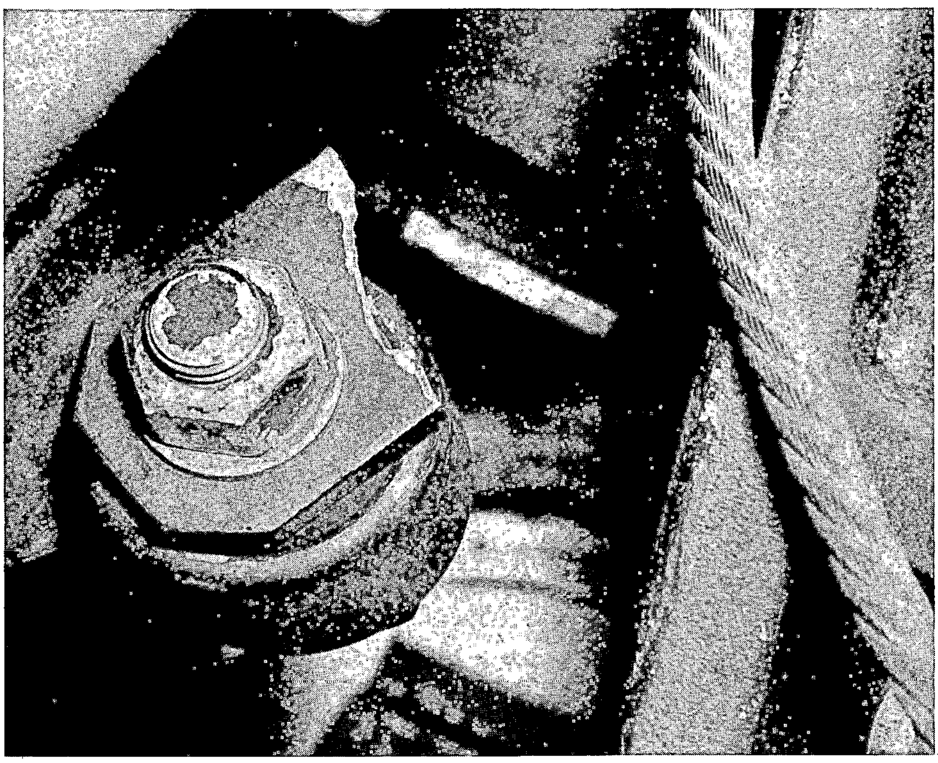


Figure 2–23. Broken Inboard Lateral Damper Bracket

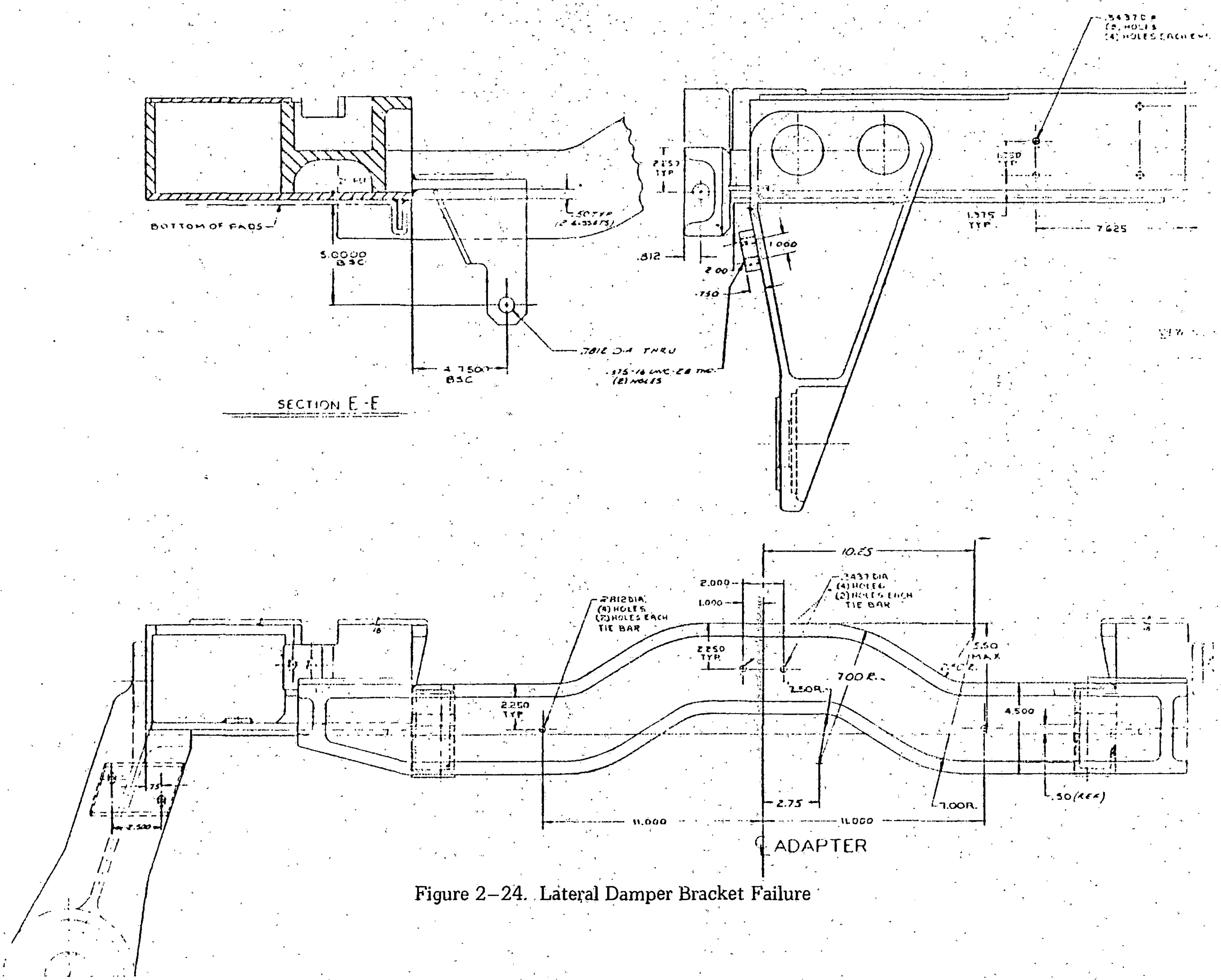


Figure 2–24. Lateral Damper Bracket Failure

The lateral damper brackets on DOTX-5 were inspected and the A-end bracket appeared bent but did not show a noticeable crack or surface blemish. The B-end bracket was bent and showed severe surface flaking from numerous bending cycles. DOTX-5 had approximately 1,250 miles of service at the time of the inspection.

A design modification was incorporated on all four trucks to stiffen the bracket torsionally. It consisted of bolting on a 3/4-inch plate as shown in Figure 2-25. New damper-to-bracket attachment bolts of increased length were fabricated to accommodate the increased bracket thickness.

2.4.2.5 Axle Mount Casting Bolts

Although inspection of one of the trucks after being detrucked revealed an interference between the outboard axle mount casting bolt and the brake caliper spider, further investigation revealed that the bolts were installed improperly (upside down) and under the carbody loading the primary suspension would deflect sufficiently for the bolt to bottom on the spider frame.

The outboard bolt, as improperly installed, was removed and the tip of the bolt was machined off such that the bolt would just protrude through the nut when reinstalled, thereby providing proper clearance.

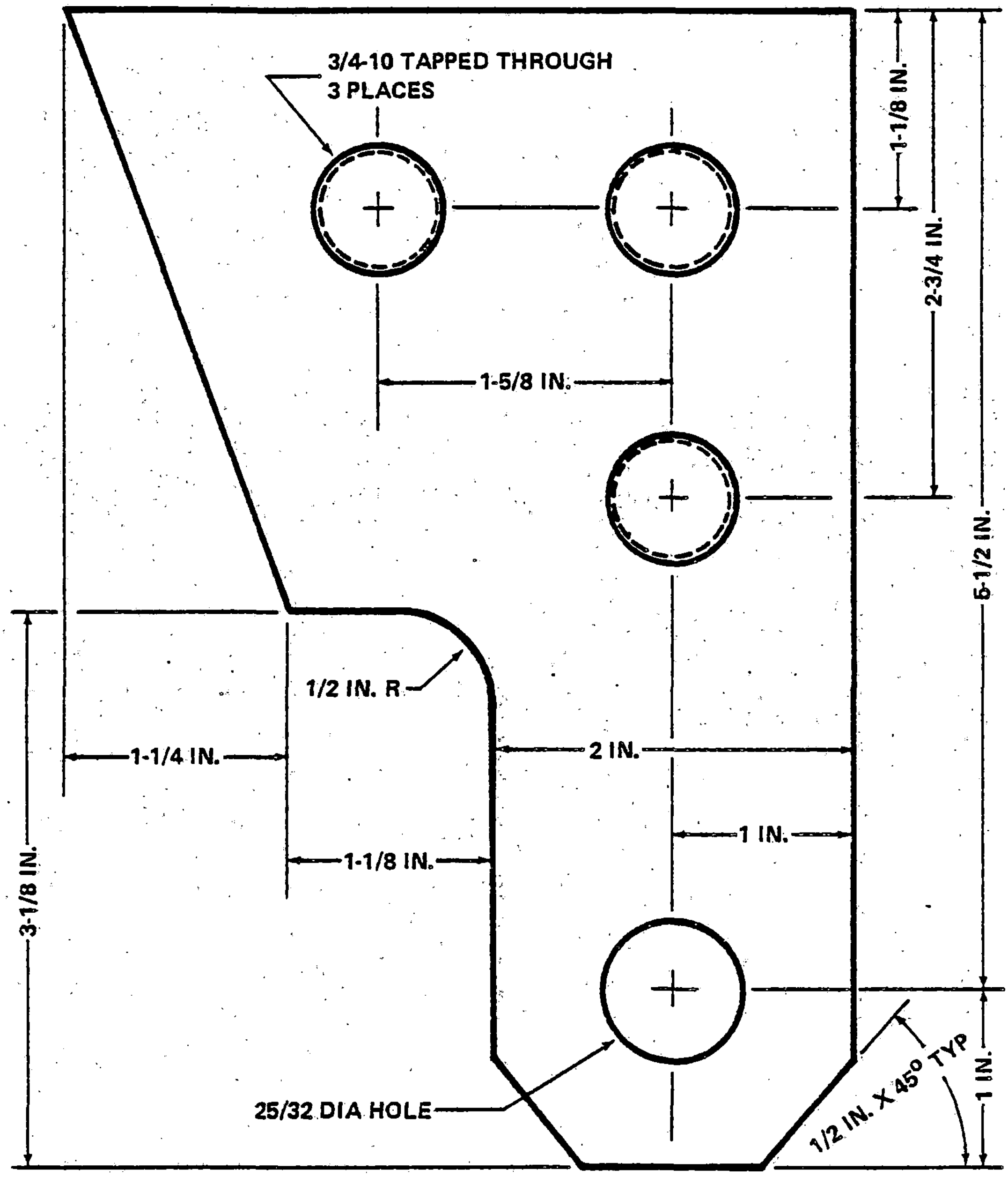
The outboard bolt cannot be installed (or removed) when the axle is assembled to the frame and therefore it was expeditious to machine the bolt tip to provide the clearance rather than disassemble. All outboard bolts on all trucks were modified in this manner. The axle installation with the cutoff bolt is shown in Figure 2-26A and the as-designed installation is shown in Figure 2-26B.

2.4.2.6 Truck/Carbody Interference

Upon removal of an A-end truck for maintenance demonstration purposes, it was discovered that a pneumatic hose support bracket (2017479-6 on right rear and 2017479-13 on left rear) had impacted with carbody structure as shown in Figure 2-27. The corners of the angle brackets were cut off at the chalk line shown in Figure 2-27A to provide the necessary clearance without reducing the bracket capability. The A trucks on both DOTX-4 and DOTX-5 were modified.

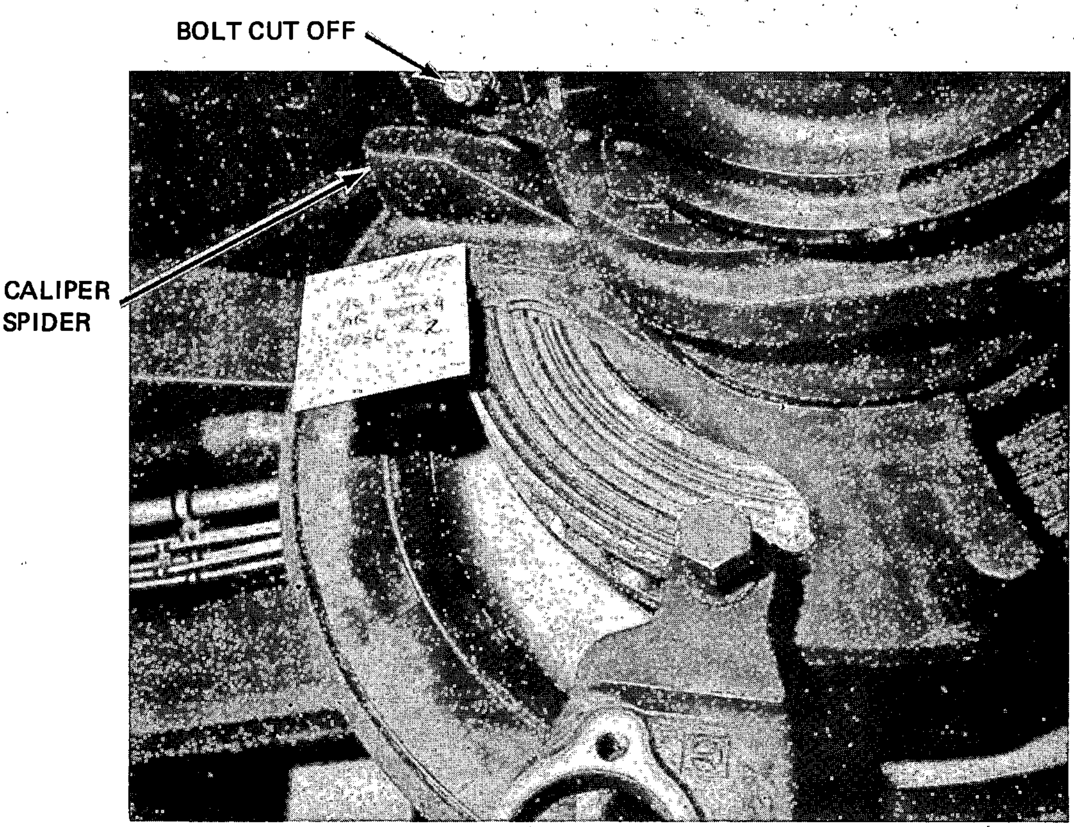
2.4.2.7 Axle Breathers

A significant amount of oil was being expelled from the axle breathers. Inspection revealed a hard rubber washer prevented the axles from breathing in a normal manner. These washers were replaced with felt washers and no further problem was noted.

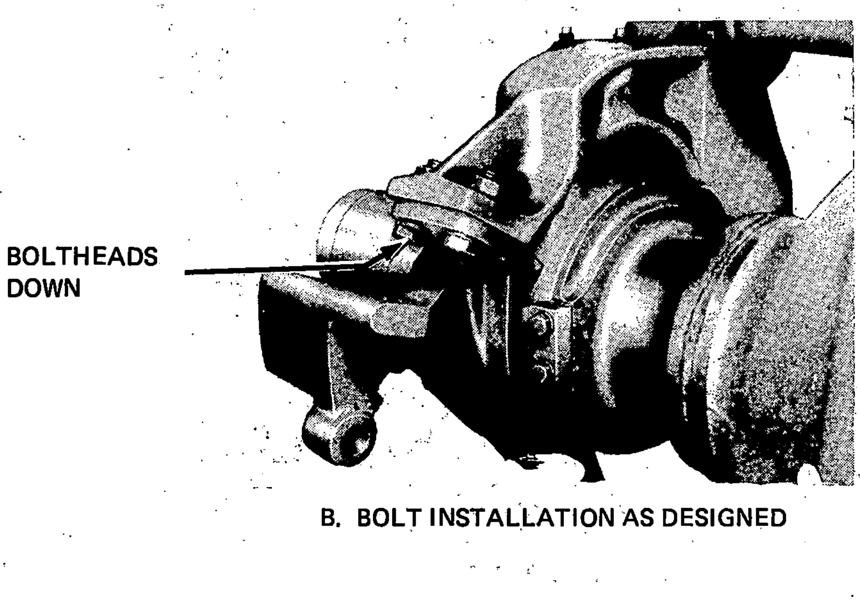


MAKE FROM 3/4-INCH THICK 4130, 4140, 4330, 4340 OR AR360
RC 34-38

Figure 2–25. Lateral Damper Bracket Repair

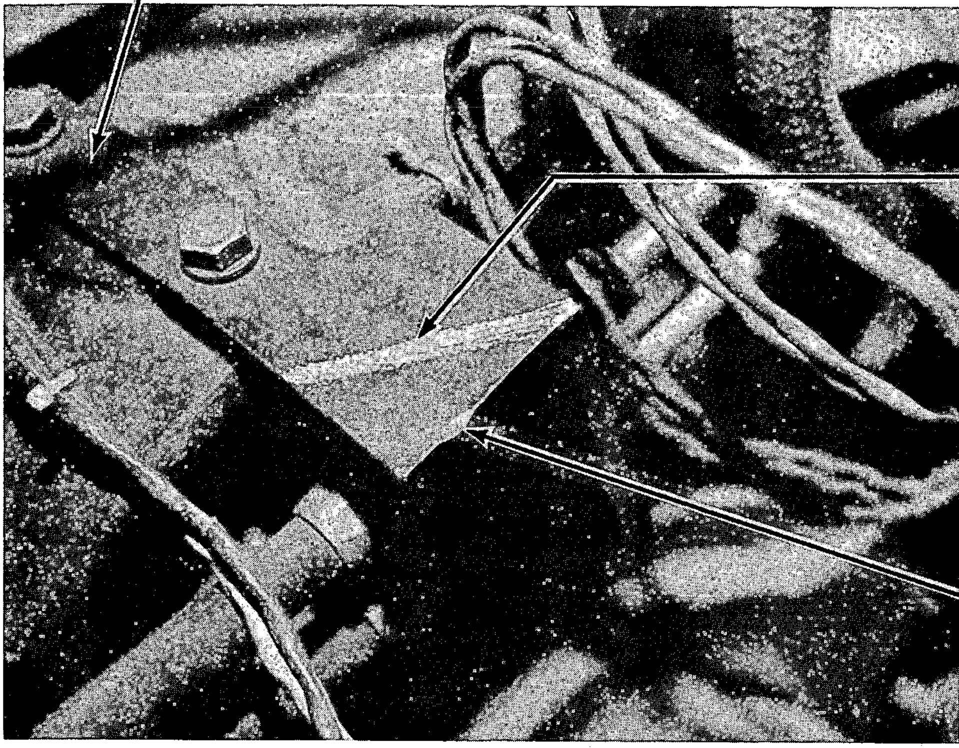


A. IMPROPER INSTALLATION OF BOLTS

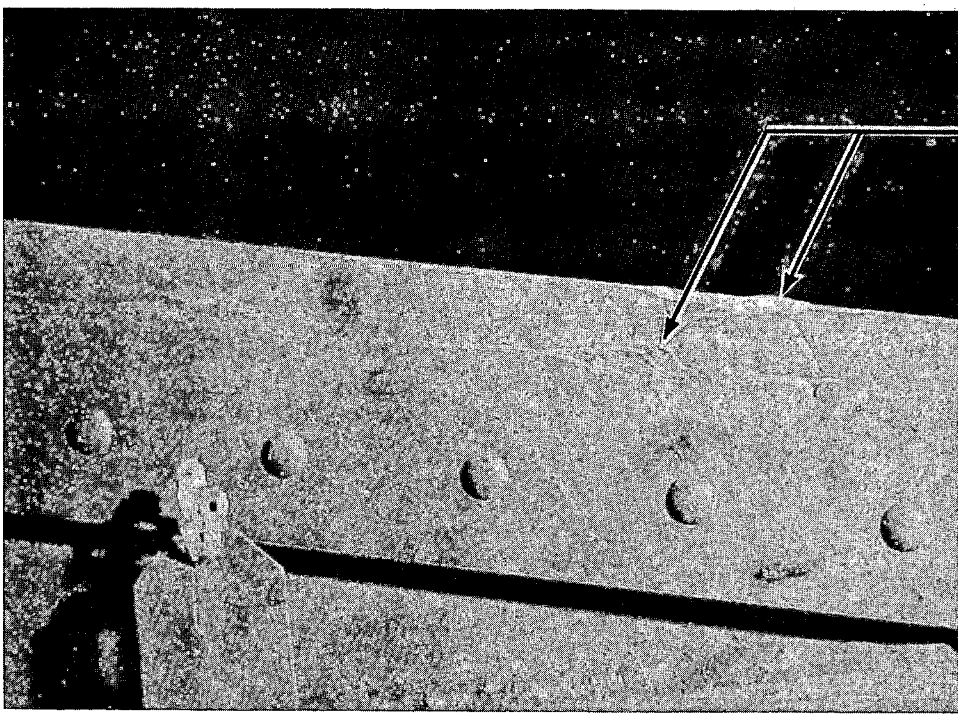


B. BOLT INSTALLATION AS DESIGNED

Figure 2–26. Axle Mount Installation



A. A-END TRUCK



B. CARBODY STRUCTURE

Figure 2–27. Truck/Carbody Interference

2.5 BRAKES AND PNEUMATICS

2.5.1 Brake and Pneumatic System Description

The ACT-1 pneumatic system provides 130-150-psi compressed air for braking, car suspension, door operation, warning, and HVAC control. Each car is equipped with a screw-type rotary compressor which feeds a single main reservoir (MR), two brake supply reservoirs (BSR), each of which stores a protected supply for six stops, and one air reservoir used in locomotive hauling. When the two ACT-1 cars are coupled as a train, they are linked by a trainline main reservoir pipe allowing full operation if one compressor in the two-car consist is inoperative. All intake valves of the compressors of a train are synchronized to prevent a single compressor accepting full air supply duty. The pneumatic system schematic is shown in Figure 2-28.

The ACT-1 air brake compressor differs from a conventional compressor in that it is powered by a shaft connected to the energy storage unit (ESU) and therefore is continuously rotating. The compressor has two modes of operation. During the charging cycle the air intake valve, as shown in Figure 2-29, is open and the separator vent line is closed, which permits the compressor to pressurize the air/oil separator which provides the air supply for the pneumatic system. When the system pressure reaches 150 psi, the air intake valve closes and the separator vent line valve opens, permitting the air/oil separator pressure to bleed off and the compressor goes into an idling mode. Check valves prevent the system pressure from venting back through the air/oil separator. When the system pressure drops to 130 psi, the charging cycle is again initiated.

The major components of the ACT-1 pneumatic system are shown in Table 2-X.

TABLE 2–X. MAJOR COMPONENT INFORMATION

Item No.	Nomenclature	Desig	Part No.	Qty	Bay Loc	Schematic No.
	Pneumatic System	–				2017158
1	Air Compressor	–	523803-1	1	11B	–
2	Coupling and Drive Shaft Assembly	–	2018483-1	1	11B	–
3	Aftercooler/Oil Cooler	–	2018066-1	1	11A	–
4	Electropneumatic (EP) Brake Unit	–	523804-1	2	3C/11C	–
5	Triple Valve	–	771-0520-9001	1	3C	–
6	Main Reservoir	MR	2000519-1	1	3A	–
7	Supply Reservoir	BSR	2000521-1	2	3B/11C	–
8	Air Reservoir	–	200530-1	1	3C	

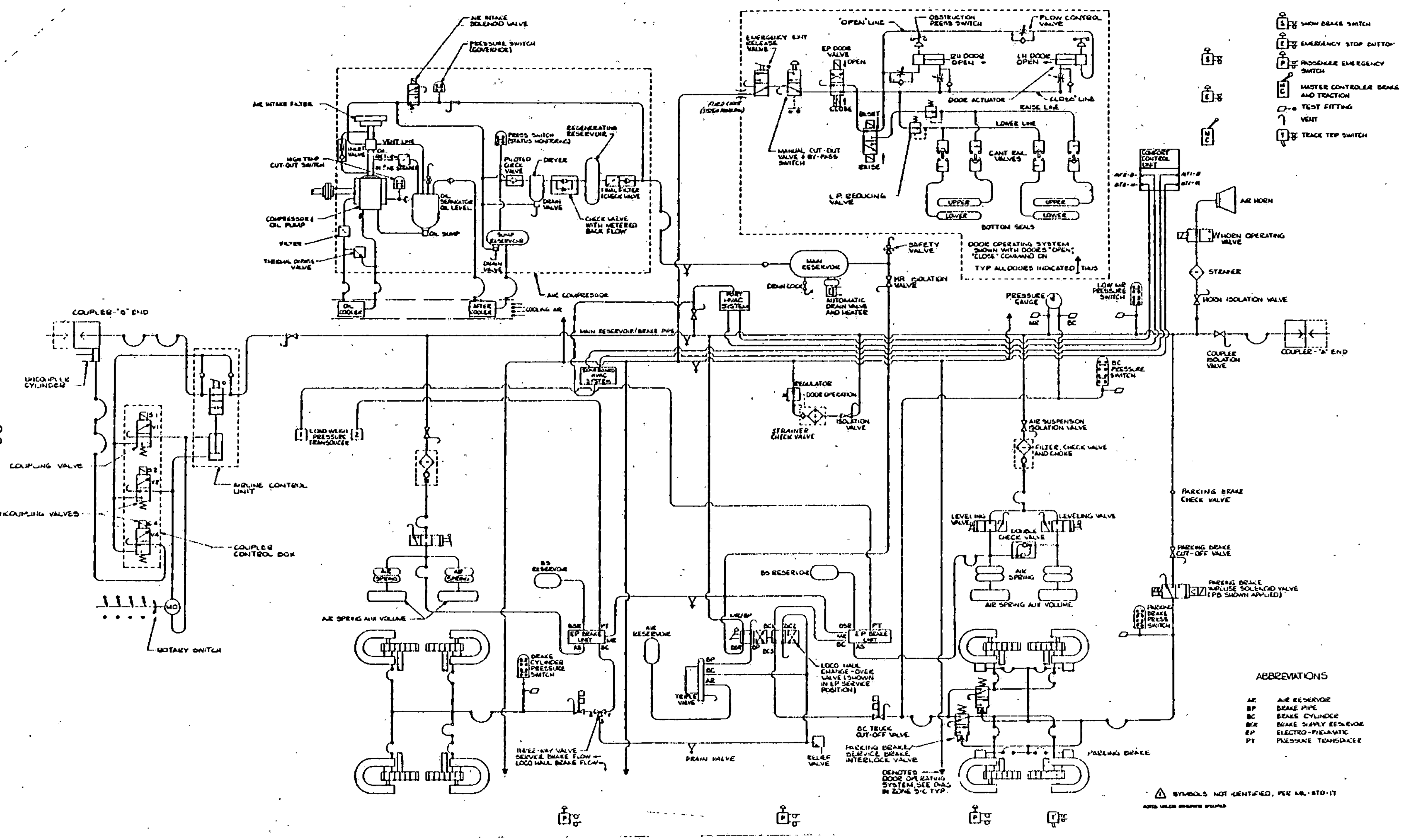


Figure 2—28. Pneumatic System Schematic

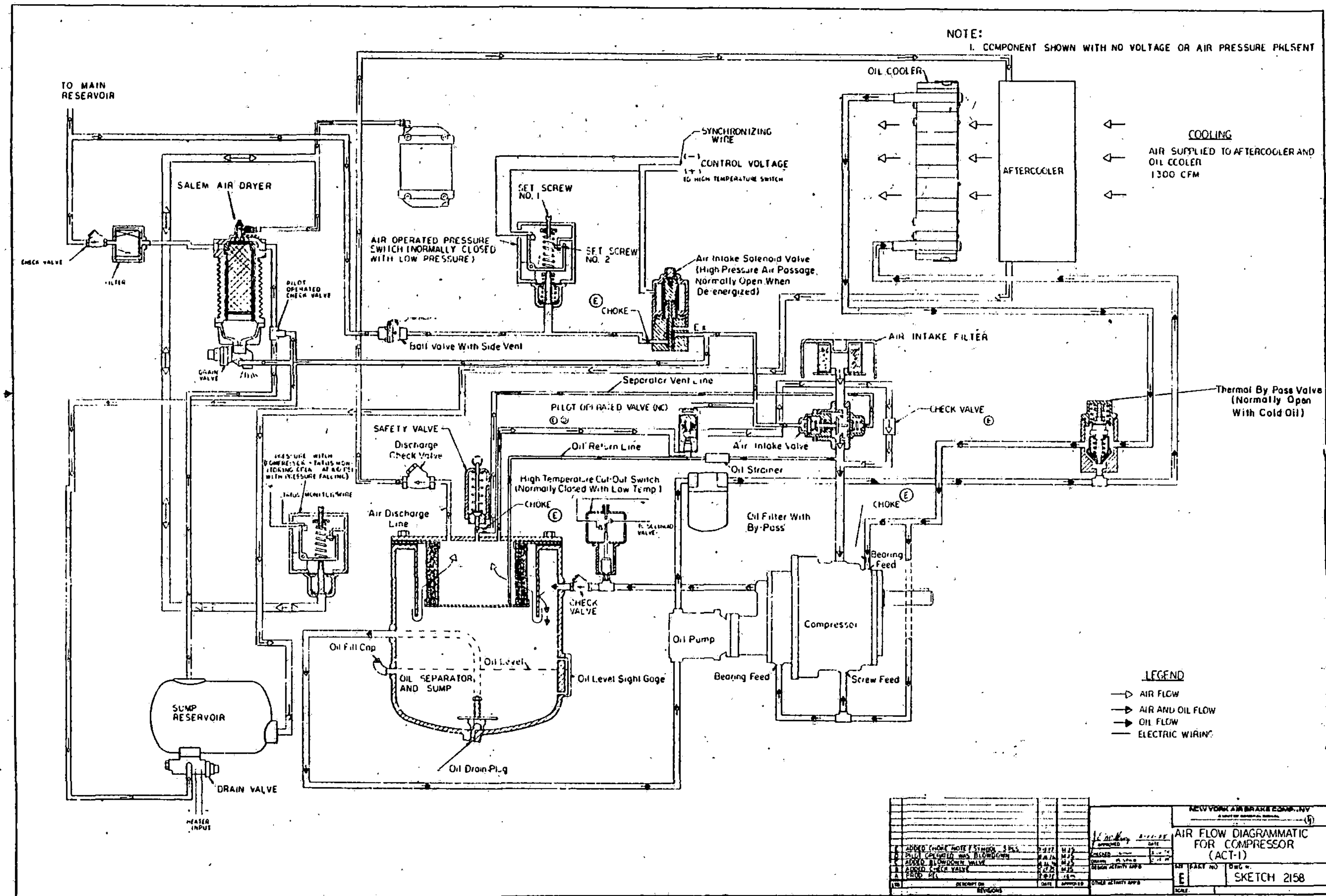


Figure 2–29. Airflow Diagram for Compressor

Normal braking on the ACT-1 railcars is provided through a combination of dynamic and friction braking systems. Dynamic braking consists essentially of commanding an electrical load from the traction motors. Friction braking is by electropneumatic -powered disc brakes acting on the moving wheel. Each brake is an air-operated, wedge-activated, automatic adjusting unit powered by one standard air chamber. However, each of the four brake assemblies on the forward truck has a spring-powered parking brake assembled piggyback over the standard air chamber. Parking brake clamp loads are provided by power springs in the parking brake calipers. Main reservoir pipe air is used to hold off the power springs via an impulse solenoid valve. In locomotive hauling, brake pipe pressure may be insufficient to hold off the parking brake; therefore, it is recommended that the parking brake be mechanically locked out during locomotive hauling.

In operation, the air chamber transmits air pressure against the wedge assembly, pushing it deeper into the actuation housing. As this happens the wedge moves between rollers and pushes them against an adjusting plunger assembly which is positioned against a pad and lining assembly. The lining rubs against the brake rotor to stop the vehicle. As brakes are applied, the braking torque is taken up directly by the brake spider and axle housing rather than the calipers. This feature eliminates caliper cocking and allows even lining wear The brake disc and caliper assembly are shown in Figure 2-30.

Two identical electropneumatic (EP) brake units are installed in each railcar; one in Bay 3C and the other in Bay 11C. An outline of the EP brake unit is shown in Figure 2-31.

The EP converter, shown in Figure 2-32, provides pilot air to the relay valve; its pressure is inversely proportional to the control current applied to the solenoid coil. The solenoid acts through a spring on a ball-metering valve, forming a variable orifice, thus modulating pressure to a pilot relay valve. This pilot relay valve, which also forms part of the EP converter, transmits control pressure to the main relay valve up to the maximum service brake cylinder pressure. A pressure-limiting valve ensures that full main reservoir pressure cannot be applied to the pilot relay valve; the air from the limiting valve first passes through a condensate trap, then through a filter and choke to the ball-metering valve. A continual controlled flow through its variable orifice to atmosphere produces a low differential pressure in the passage between the metering and the pilot relay valve; this low pressure is counteracted by a bias spring above the relay valve diaphragm, ensuring positive cutoff at the inlet valve seats. A thermostatically controlled heater prevents freezing of condensate in the valve. The fully modulated output pilot air at brake cylinder pressure level passes through the emergency magnet valve.

On its passage from the EP converter to the relay valve, the pilot air passes through the emergency magnet valve (EMV) which remains energized during normal service; when the EMV is deenergized, either to produce an emergency brake application or when the car is in layup, main reservoir air is passed through the EMV to the emergency variable load valve. All EMV's are trainlined through the continuity wires which can be opened by any of the following switches to initiate an emergency stop:

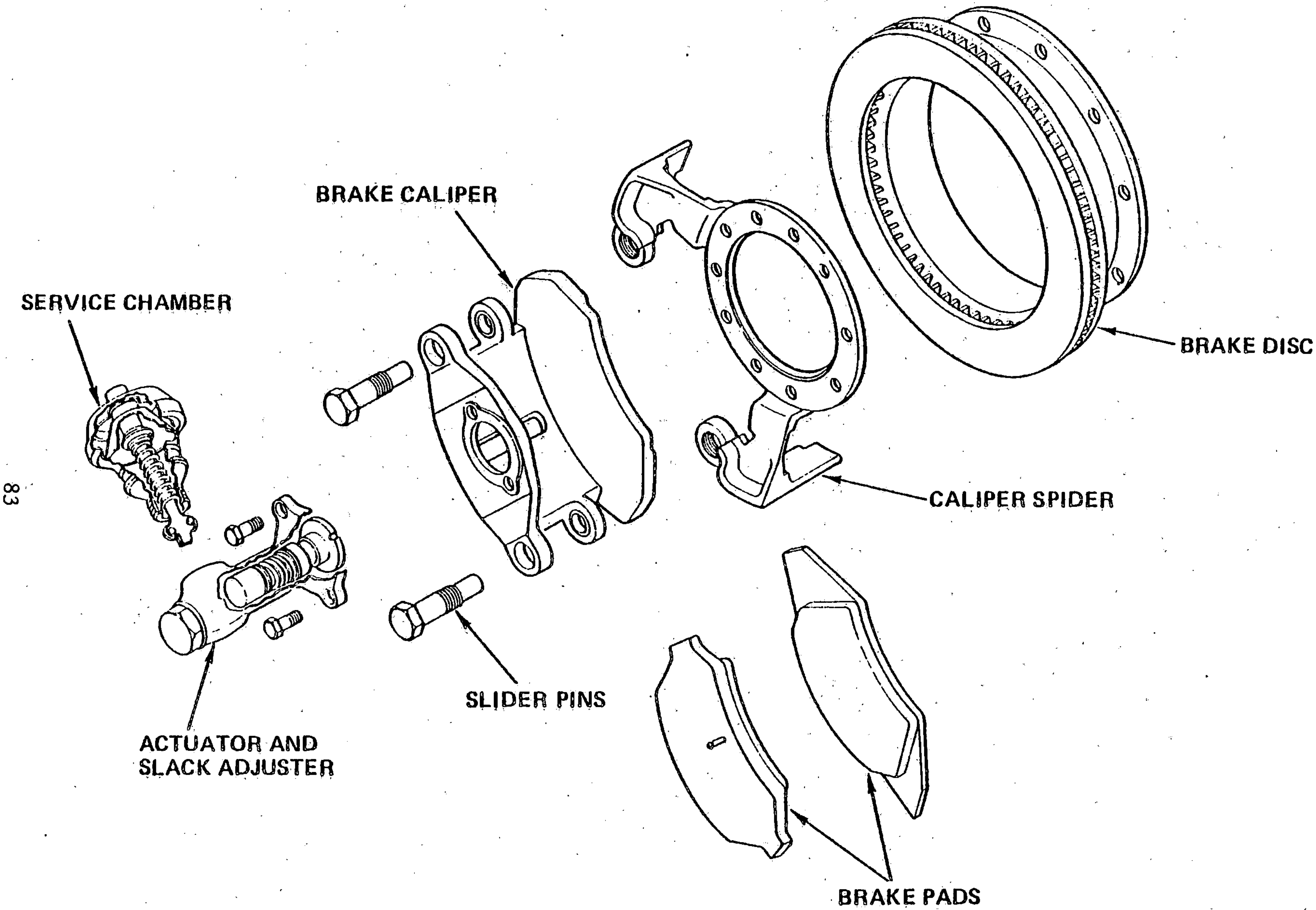


Figure 2–30. Brake Disc and Caliper Assembly

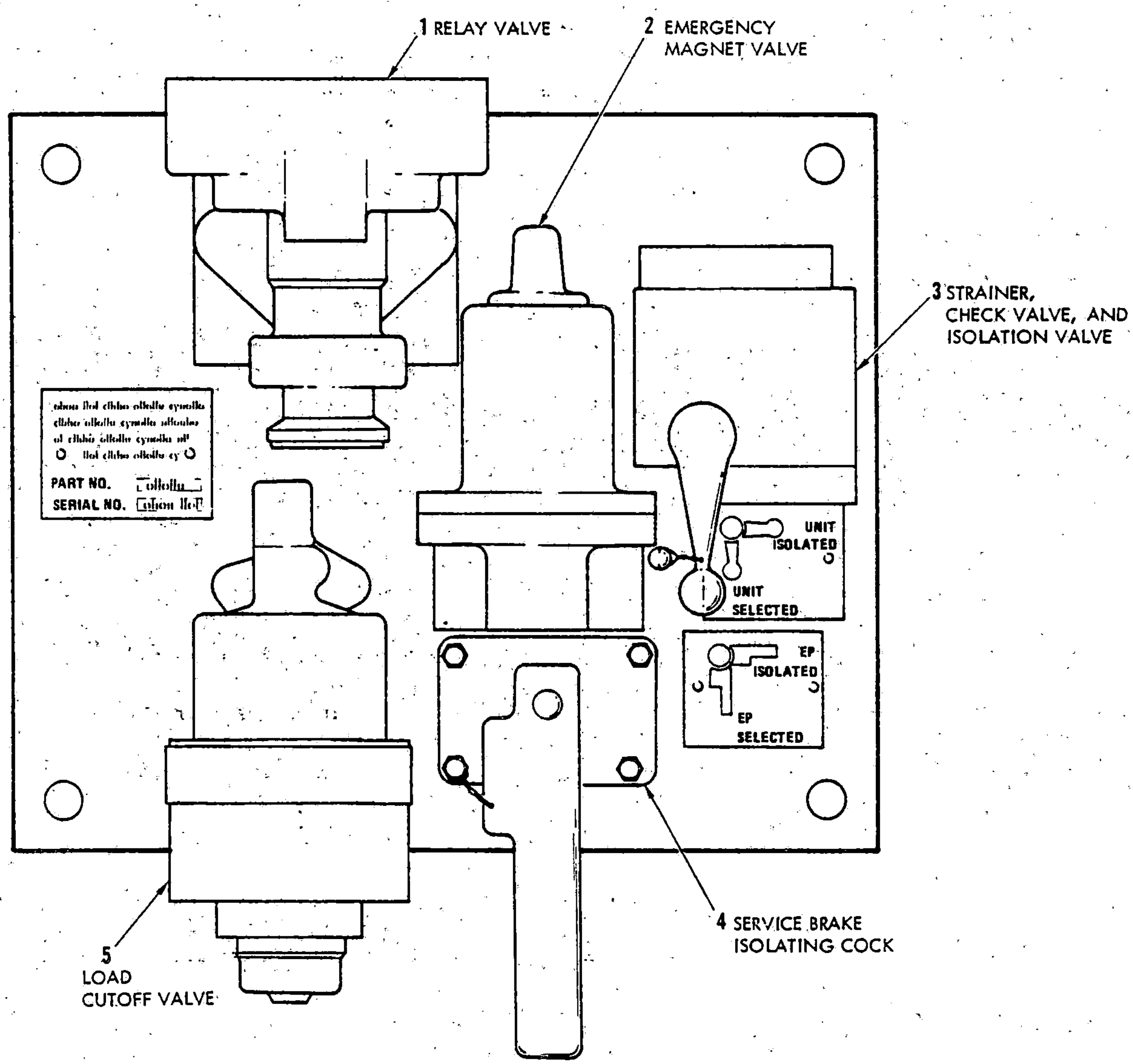


Figure 2–31. EP Brake Unit

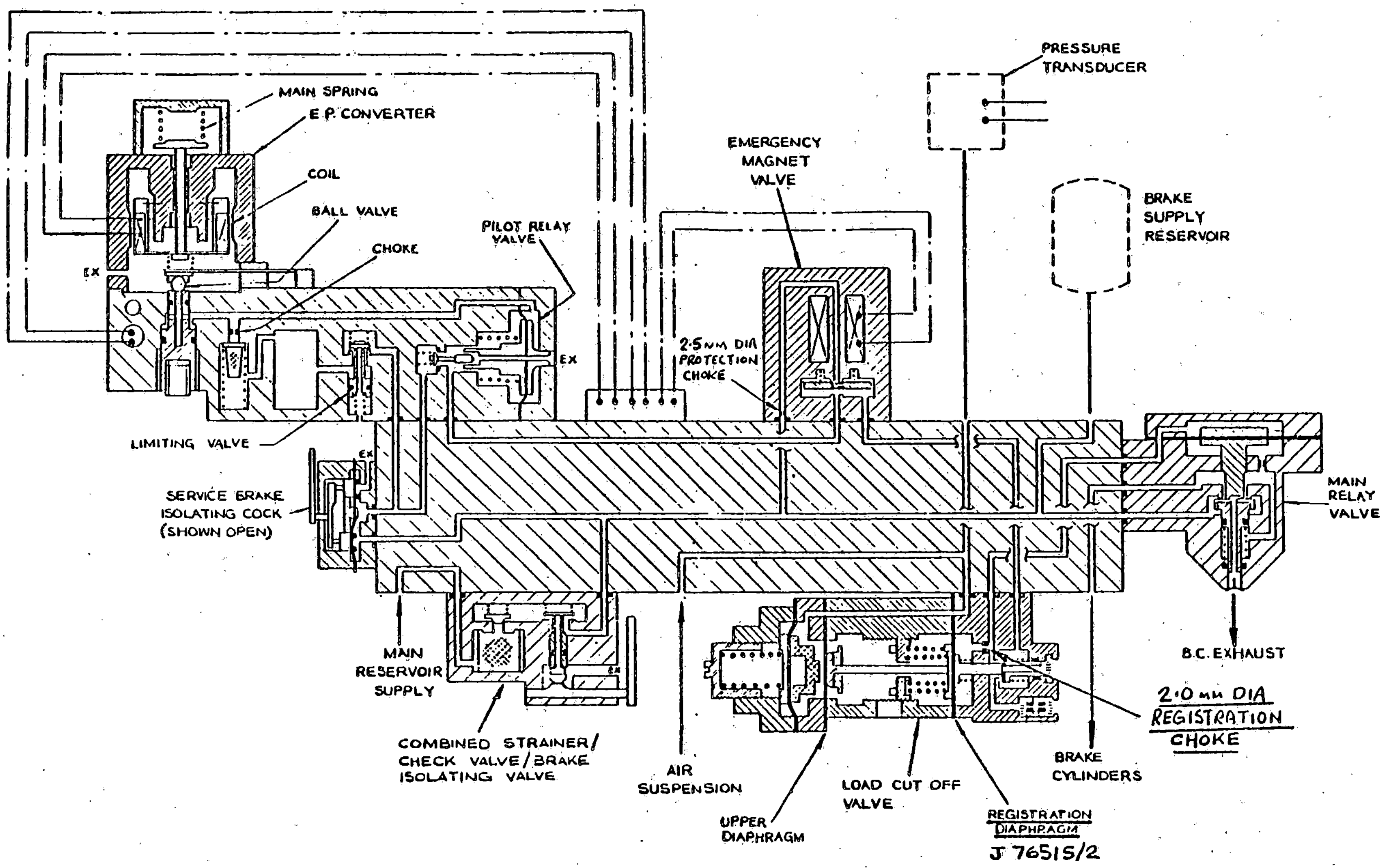


Figure 2–32. EP Brake Unit Flow Diagram

1. Track trip switch
2. Emergency switch (panic button)
3. Passenger emergency switch (three locations)
4. MC emergency
5. Hostler emergency switch
6. Low MR pressure switch
7. Coupler separation (accidental)

The main function of the emergency variable load valve (EVLV) is the control of pilot air pressure to the relay valve proportional to vehicle weight. This weight information in the form of truck air-spring pressure is communicated to a supplementary diaphragm chamber in the EVLV which keeps a load-weighing spring compressed. As pilot pressure builds up between the emergency magnet valve and the relay valve, it also registers on the main diaphragm, acting in opposition to the main spring under the main diaphragm; on balancing, the inlet valve laps, preventing a further pressure increase to the relay valve. During an emergency application, the valve is self-maintaining, thereby compensating for any leakage. The EVLV does not affect any service brake pressure up to its maximum value, since the inlet valve, under the control of the supplementary diaphragm, is adjusted approximately 17 percent higher than the service brake pressure based on the same load. During brake release from either emergency or service braking, the pilot air pressure is first reduced by energizing the EP converter, which allows the pressure in the relay valve port to lift the inlet/exhaust valve spool of the EVLV, thereby allowing air from the relay valve to vent, both directly throughout the EVLV and through the EP converter, thus accelerating brake release. Any loss of air suspension pressure causes the supplementary diaphragm, now acted on by the load-weighing spring, to open the inlet valve to its full AW3 load position. This means that in case of air pressure loss the friction brake system automatically responds with a brake rate equivalent to an AW3 loading condition in any emergency mode and with a service rate corresponding to the highest air-spring pressure monitored in the ECU.

The relay valve functions as a volume amplifier. Pilot pressure from the emergency variable load valve acting on the top side of the valve diaphragm unseats a hollow valve spindle from its soft seating, thereby admitting brake supply reservoir air to the brake cylinder (BC) line and through a registration choke to the underside of the diaphragm, thereby balancing pilot and output pressures. Conversely, when pilot air pressure is reduced to effect a brake release, pressure in the BC line acting on the underside of the diaphragm first returns the hollow valve spindle to its seating, thereby cutting off brake supply reservoir air, and then continues to open the central port of the hollow spindle which vents the brake cylinder line and, in so doing, releases the brakes.

A combined air strainer, check valve, and isolating valve is mounted on each EP brake unit to isolate all components of that unit as well as the brake supply reservoir from MR supply pressure under manual control.

All initiation methods of ACT-1 emergency braking are applied at a rate of 3.5 mphps and are not jerk-limited in release or reapplication. Emergency-braking modes with and without slide protection are shown in Table 2-XI.

All modes of emergency braking are irretrievable, requiring as a minimum the closing of the no-motion relay and moving the master controller into full service braking position. Stops initiated by the low-MR-pressure switch require investigation of cause of pressure loss and subsequent isolation of the affected part of the system before the railcar can be moved; similarly, a passenger emergency switch-initiated stop will need investigation and resetting of the switch. The track trip switch resets automatically after tripping; along with all other components of the emergency circuits, it contains a double-pole switch which interrupts the B+ and return line.

2.5.1.1 Locomotive Hauling Braking

When railcars are hauled in train with other railcars without onboard electrical power or air pressure, the energy to operate the brakes is supplied in form of air pressure at 70 psi from the hauling vehicle (locomotive). To match the high brake performance of transit cars to freight cars with their lower brake rates, the hauling locomotive retardation must be derated to 1.0 to 1.5 mphps. This prevents overheating of transit car brakes over the longer brake distances required by the freight train brakes and also provides drag forces similar to those of the freight train in areas having frequent grade changes, where low levels of braking must be applied to avoid coupler banging.

To change from service braking to locomotive haul braking, a loco haul changeover valve (see Figure 2-33) is provided which has the following functions:

1. In service mode:
   a. To connect main reservoir to the MR pipe and to both BS reservoirs.
   b. To vent the brake pipe chamber of the triple valve.
   c. To connect the EP brake unit (EPBU1) to the brake cylinders of the A-end truck.
   d. To vent the brake cylinder chamber in the triple valve.

2. In loco haul mode:
   a. To vent lines to the main reservoir and to both EP brake units.
   b. To connect the main reservoir/brake pipe to the brake pipe chamber in the triple valve.
   c. To vent the EPBU1 (BC connection).
   d. To connect the triple valve to the brake cylinder of the A-end truck.

TABLE 2–XI. EMERGENCY BRAKING MODES

Emergency Initiation Method	Slide Protection	Component	Number Per Car	Location	Method of Reset
Emergency, Motorman	No	Emergency brake switch	1	Motorman console	Manually pull knob outward when car is at standstill and MC is in full service.
Low Main Reservoir Pressure	No	Pressure Switch	1	Undercar bay 1C	Pressure rise above 110 psi. MC in full service.
Track Trip	No	Track trip switch	1	A-end truck location depends on property	Automatic reset MC in full service.
Passenger Emergency	No	Passenger Emergency switch	3	Right door post, all left doors	Illuminated when operated. Driver key reset. MC in full service.
Master Controller	No	Master controller	1	Motorman console	MC in full service.
Deadman Emergency	Yes	Deadman handle	1	Motorman console	MC in full service.
ATO	No	Signal coil	1	A-end truck	Automatic reset. MC in full service.
Train Separation (accidental)	No (trail car) No (lead car)	Electric coupler	1	B end	Recoupling. MC in full service.
Train Separation (Decoupling)	No (trail car) controlled by motorman (lead car)	Electric coupler	1	B end	–
Hostler	No	Hostler emergency switch	1	B-end hostler panel	Automatic reset when car stops moving.

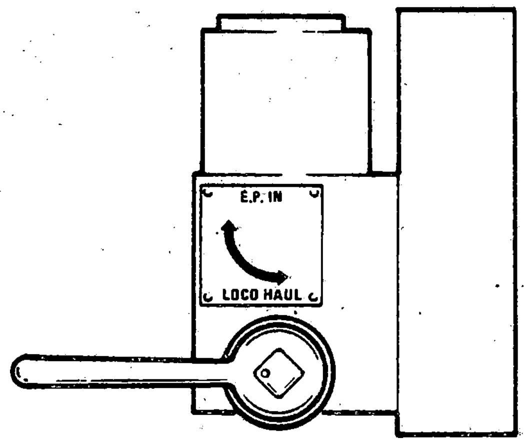


Figure 2–33. Six-Way Changeover Valve

NOTE: Isolation of the B-end EP brake unit (EPBU2) is effected through a separate 3-way cock which also serves to connect the triple valve to brake cylinders of the B-end truck. Both angle cocks at the ends of the MR pipe must be open to allow the latter to act as brake pipe during loco hauling, unless the ACT-1 railcar is last in the train; in that case, the angle cock of the uncoupled end must be closed.

The six-way changeover valve is installed adjacent to the EP brake unit in bay 3C. As shown in Figure 2-33, the placarding adjacent to the valve handle reads EP IN and LOCO HAUL, with a directional arrow. For normal service braking the handle must be set in the EP IN position. When the railcar is being towed by a locomotive, the valve handle must be set in LOCO HAUL position to provide air pressure derived from the hauling vehicle to the brake system.

The locomotive haul systems design is based on a brake pipe (trainlined) pressure of 70 psi and a full brake pipe pressure reduction of 25 psi; at this reduction the reservoir supplying brake cylinders (BC) must equalize in a single application. Such equalization of a BC pressure of 26 psi, which is needed to produce a brake rate of 1.5 mphps under AW0 loading conditions, cannot be provided by the regular brake service reservoir with its requirements for a minimum of six emergency stops at low AW3 loads. A smaller air reservoir is therefore provided for this function. Since full venting of the brake pipe would produce excessive BC pressures, a relief valve with a cracking pressure set to 30 psi is provided to match ACT-1 emergency rates in loco hauling to those of the freight train.

2.5.1.2 Brake System Coupling Requirements

Coupling of ACT-1 railcars at the A end is accomplished by buffing. Decoupling is performed manually by operating the decoupler lever. The coupler isolation valve shall remain closed unless cars are coupled to match vehicles for loco hauling, in which case coupler isolation valves shall be open to permit the MR pipe to be used as trainlined brake pipe.

Coupling at the B end of the ACT-1 railcar is accomplished by buffing, but decoupling is effected by switch operation on the hostler panel. This initiates a sequence, commencing with closing the main reservoir pipe, turning a switch to close all necessary loop circuits, and finally opening the coupler hook. Decoupling can also be accomplished manually by operating the decoupler lever.

2.5.1.3 Slide Protection

Wheel slide protection is provided independently and simultaneously to the dynamic and friction brake systems. Two forms of protection are available: full slide control which includes adaptive control when the vehicle is in service braking, and a restricted form of slide control for the various modes of emergency braking as listed in Table 2-XI.

Full slide control permits fast dumping of BC pressure through the relay valve in the EP brake unit. Each truck is fitted with a speed sensor to detect retardation in excess of the commanded brake rate. This information is processed in the ECU to apply a release signal to the EP converter; the latter reduces pilot pressure to the relay valve in the EP brake unit which in turn dumps BC pressure, thus releasing brake discs and wheels. To prevent the start of a regenerative slide cycle, reapplication of brake pressure, after such dumping, to the full command level cannot be applied until the remnant rail adhestion has reaccelerated the rotating truck masses (wheels, discs, axles, couplings, gears, and motor) to full rolling speed. BC pressure is therefore initially raised to approximately 80 percent of the value which initiated the last slide cycle. Adaptive control to the EP converter then ramps up application pressure at a low jerk limit to the full BC pressure, equivalent to the brake command level.

Such adaptive control is available in service braking, but is omitted in emergency braking; there, only simple ON-OFF control in the EP converter is provided for those emergency brake modes that include slide protection. Rapid venting to release brake effort in both service braking and emergency mode with slide control is performed by both the EP converter and the emergency variable load value.

2.5.1.4 Airspring Suspension System

The airspring suspension system for each truck consists of four airsprings mounted between the truck frame, which serves as the air reservoir for the airsprings and suspension adapter. In operation, the suspension adapter transmits lateral and longitudinal forces from the carbody to truck with vertical loads being transmitted directly over the airsprings.

Two leveling valves at the A-end truck and one leveling valve at the B-end truck control operating height and air pressure to compensate for variable passenger loads. Should one of the airsprings become ruptured, all the airsprings on the B-end truck will deflate. In this event, rubber bumpers within each airspring will prevent metal-to-metal contact. On the A-end truck, the left and right pairs of airsprings are supplied independently, crossflow being prevented by a double check valve. If one pair of airsprings experiences total air pressure loss, the opposite pair will be vented through the double check valve to within 30 psi of atmospheric pressure.

In the event of airspring pressure loss, the friction system automatically responds in any emergency mode with a brake rate equivalent to AW3 (crush load) condition, and with service brake rate corresponding to the highest airspring pressure monitored in the car electronic control unit (ECU).

CAUTION

WHEN OPERATING ACT-1 CARS ON TRANSIT PROPERTIES, THE SIX-WAY CHANGEOVER VALVE (LOCO HAUL VALVE) MUST BE IN THE E.P. IN POSITION AND SAFETY-WIRED.

2.5.1.5 Brake System Control

Service braking is initiated from the master controller. Signal is in the form of a P current and a digital drive trainline command. These signals enter the electronic control unit (ECU) where the P signal is adjusted for car load derived from the higher of the two air suspension pressure signals. This load-adjusted signal is then summed with the dynamic brake tractive effort signal so that the difference is scaled to drive the EP converter. The EP converter current varies linearly from 0.23 amp at full brake release to approximately 0.03 amp at full service braking at crush loading (AW3). The EP converter current is jerk-limited and provided with an adaptive slide control in the service brake mode. Jerk limitation during service application or release is designed not to exceed 2 mphpsps. The EP converter current is also modified to command inshot pressure which readies the caliper pads for instant application and to command snow brake pressure after selection by the motorman. The basic controls of the friction brake system are shown in the block diagram, Figure 2-34.

The four floating calipers and discs on each truck are served by an individual EP brake unit which receives individual commands from the ECU. The air, which reaches a maximum pressure of 90 psi under AW3 (crush load) emergency braking conditions, registers on a diaphragm in the brake chamber which transmits the disc clamping loads through a wedge-and-roller mechanism to a set of friction pads; floating action of the caliper permits application of clamp forces from one side only. The braking energy of each railcar is dissipated through eight chrome-copper-alloy discs, with four discs and calipers serving also as parking brakes on the A-end truck.

2.5.1.6 Friction Brake System

Four basic functions of the friction brake system operate as described below:

1. Blending with dynamic braking to match the command level: Under normal conditions, friction braking is restricted to approximately 15 percent of brake effort under AW3 load conditions at a speed of 80 mph, decreasing to zero at approximately 75 mph and to all-friction-braking at crawl speed down to a full stop.

   Note

   During any normal braking, if the flywheels become fully charged, friction brakes will complete the stop.

2. Sole responsibility for stopping and retardation when dynamic braking is inoperative.

   In this mode there is sufficient capacity to operate a car under AW1 loading conditions over a round trip, typically specified over a distance of 18.5 miles in 38 minutes, allowing 20 seconds dwell at each of 28 stops, and reaching maximum speed wherever traction conditions allow. Service braking is automatically available following deficiency or loss of dynamic braking.

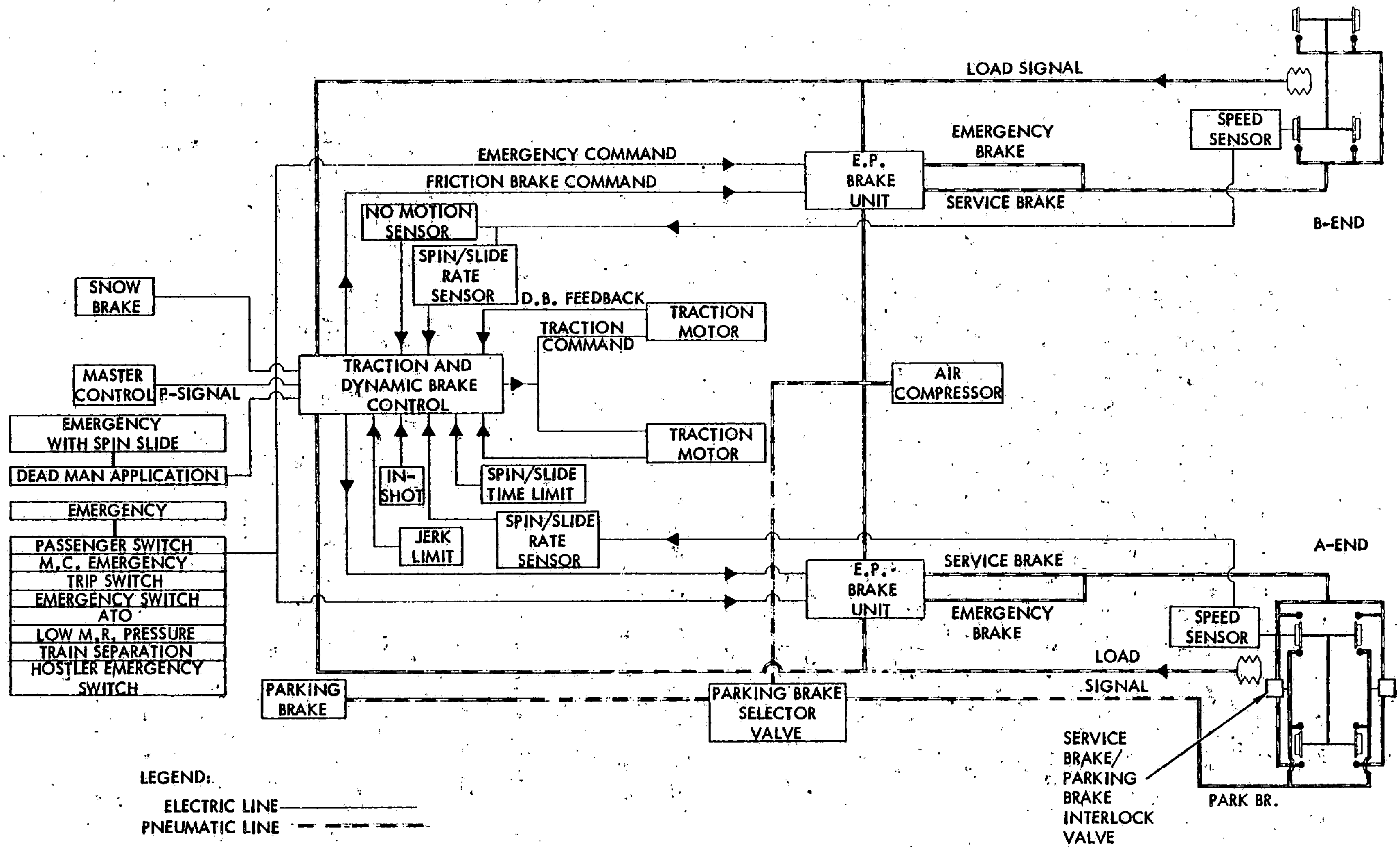


Figure 2–34. Friction Brake System Block Diagram

3. Emergency braking:

   Dynamic braking is eliminated in all emergency modes and an irretrievable stop is commanded which cannot be overridden until released by the no-motion circuitry.

4. Parking brake application in layup:

   The parking brake effort is supplied by a power spring which is held released by air pressure applied to a diaphragm-operated parking-brake actuator. An impulse-type solenoid valve is momentarily energized by battery voltage. The twin solenoid valve is latched in either brake applied or brake released position. In the absence of hold-off air pressure, the parking brake can be individually released by turning a screw mechanism inside the caliper actuator. (With air pressure applied, the screw mechanism can be turned more easily.) The air pressure required to hold off the power springs also registers on a pressure switch to indicate that parking brakes are fully released before traction power can be applied to the railcars. An interlock valve, activated by the air pressure which releases the spring brake, is used to vent the service brake chamber of the A-end truck, thus preventing service brake and parking brake clamp loads being applied simultaneously to the brake caliper.

2.5.1.7 Emergency Brake Operation

Initiation of emergency braking is made electrically and brake pipe venting is not used in the ACT-1 system. The emergency magnet valve is deenergized to route BSR air to the brake cylinders; therefore it bypasses the EP converter which alone can provide slide control for all emergency brake modes with slide protection. Only basic electronic slide control is retained to minimize electronic failure risks; the EP converter therefore is commanded to dump or to resupply control air at a pressure equivalent to emergency rates at AW3 loading, the pressure then being modulated downstream in the emergency variable-load valve (EVLV) to suit the actual car weight.

2.5.2 Final Configuration

The ACT-1 pneumatic system configuration as delivered to the Transportation Test Center is defined by AiResearch pneumatic system schematic 2017158, Revision D, undercar plumbing installation 2017151, Revision H, and plumbing installation, secondary air and brakes, 2017479, Revision G. The test program at TTC necessitated some pneumatic air brake system changes which are defined below and summarized in Table 2-XII.

2.5.2.1 Main Reservoir Quick Disconnect

To facilitate the checkout and troubleshooting of the pneumatic system, a quick-disconnect fitting was supplied by TTC and added to the main reservoir drain valve (part no. 771-0519-9001) to permit using shop air to charge the pneumatic system.

TABLE 2–XII. FINAL CONFIGURATION CHANGES TO BRAKES AND PNEUMATICS OF DOTX-4 AND DOTX-5

Original Part No.	Component	Changed to
771-0519-9001	Added quick disconnect to MR drain valve	–
Rockwell A1-3299-L-4952X	Changed parking brake chamber from 24-sq-in. to 30-sq-in. units	–
2017288-1, Rev A	Air compressor drive shaft	2018483
Westcode D76084/1	Variable load cutoff valve diaphragm	–
B80966/5	Follower size changed	–
55028	Main reservoir check valve	Spring and valve seat removed

2.5.2.2 Parking Brake Chambers

The actuator housing and failsafe chamber assemblies (Rockwell specification control drawing A1-3299-L-4952X) on the A-end trucks contained a piggyback parking brake chamber (Anchor Loc 1X20-3276-P-16X) with a 24-square-inch surface. The parking brake retarding force developed by these chambers was found to be inadequate and therefore they were replaced by a similar chamber of 30-square-inch size. All four chambers on both A trucks were replaced.

2.5.2.3 Air Compressor Coupling Assembly

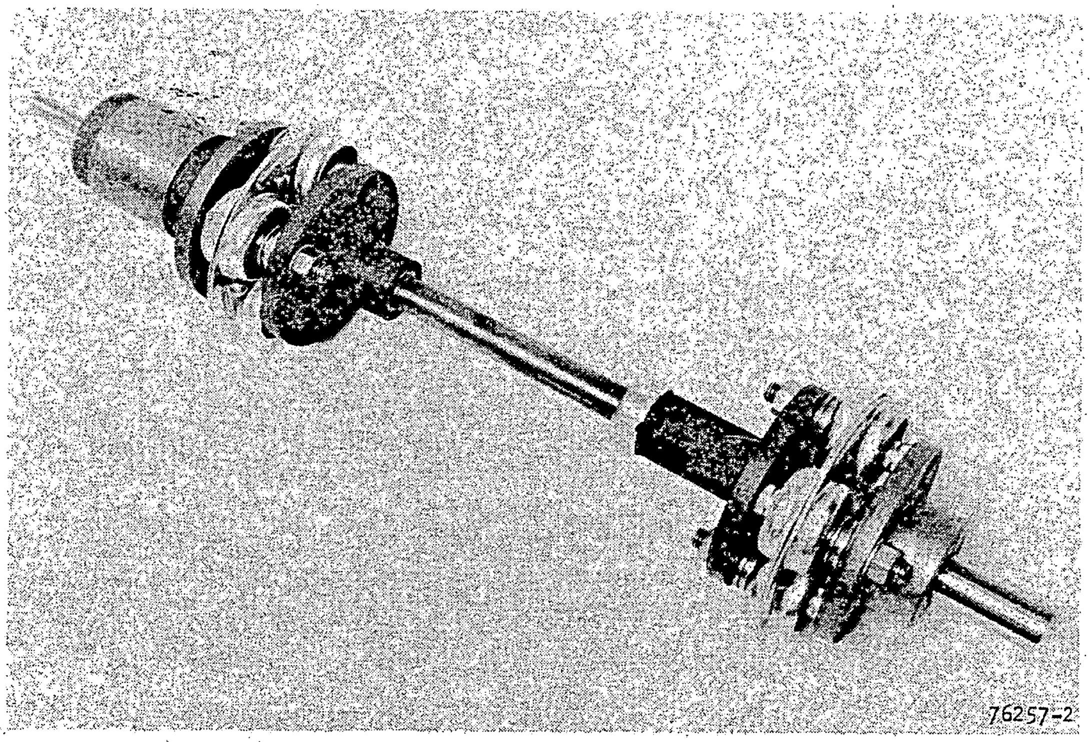
The air brake compressor is shaft-driven by the ESU. Early testing revealed a dynamic unbalance problem with the shaft assembly and the resolution was a redesigned assembly which was approximately one-third the weight of the original design. The original shaft (2017288-1, Revision A) and the new design (2018483) are shown in Figure 2-35.

2.5.2.4 Variable Load Cutoff Valve

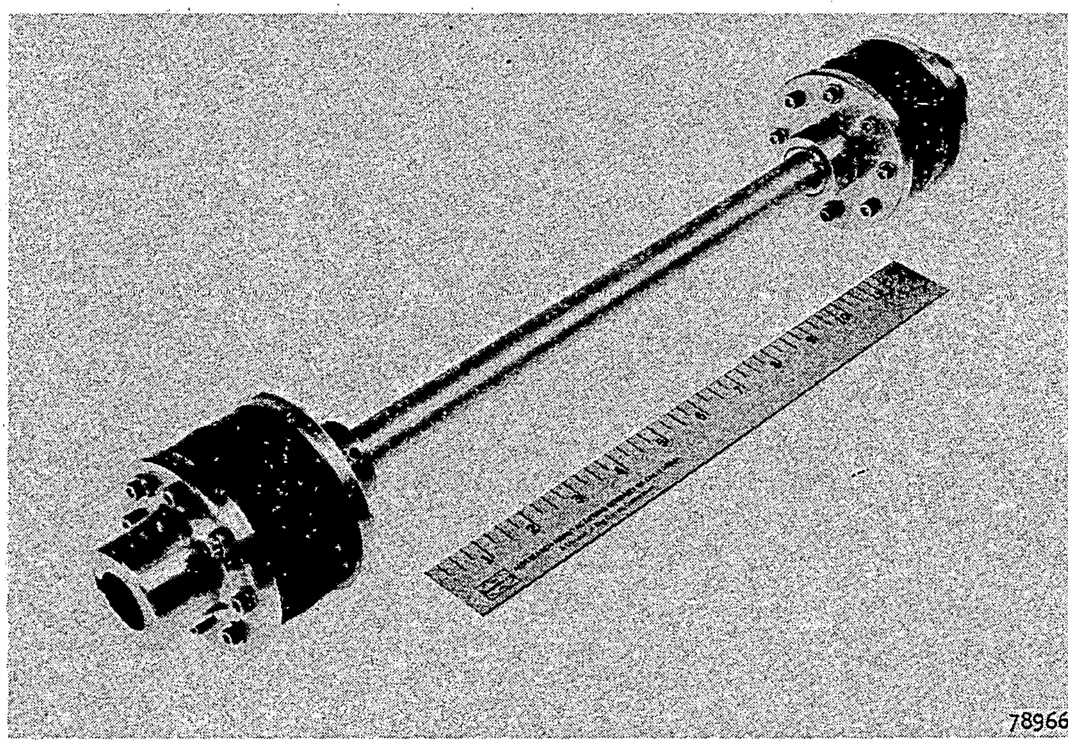
The increase in the car empty weight required changing the output slope of the variable load cutoff valve (Westcode drawing D76084/1). In order to accomplish the slope change, Westcode supplied a modified diaphragm follower (Westcode drawing B80966/5). The modification has been incorporated into both cars. Figure 2-36 shows a cutaway of the EP converter with the diaphragm follower noted.

2.5.2.5 Air Compressor Trainline

Operation of the ACT-1 as a two-car consist revealed that the two air compressors were synchronized through the pressure switch on each compressor, but a check valve between the switch and the main reservoir permitted the lead compressor to overpressurize the main



a. ORIGINAL CONFIGURATION



b. FINAL CONFIGURATION

Figure 2–35. Brake Compressor Drive Shaft

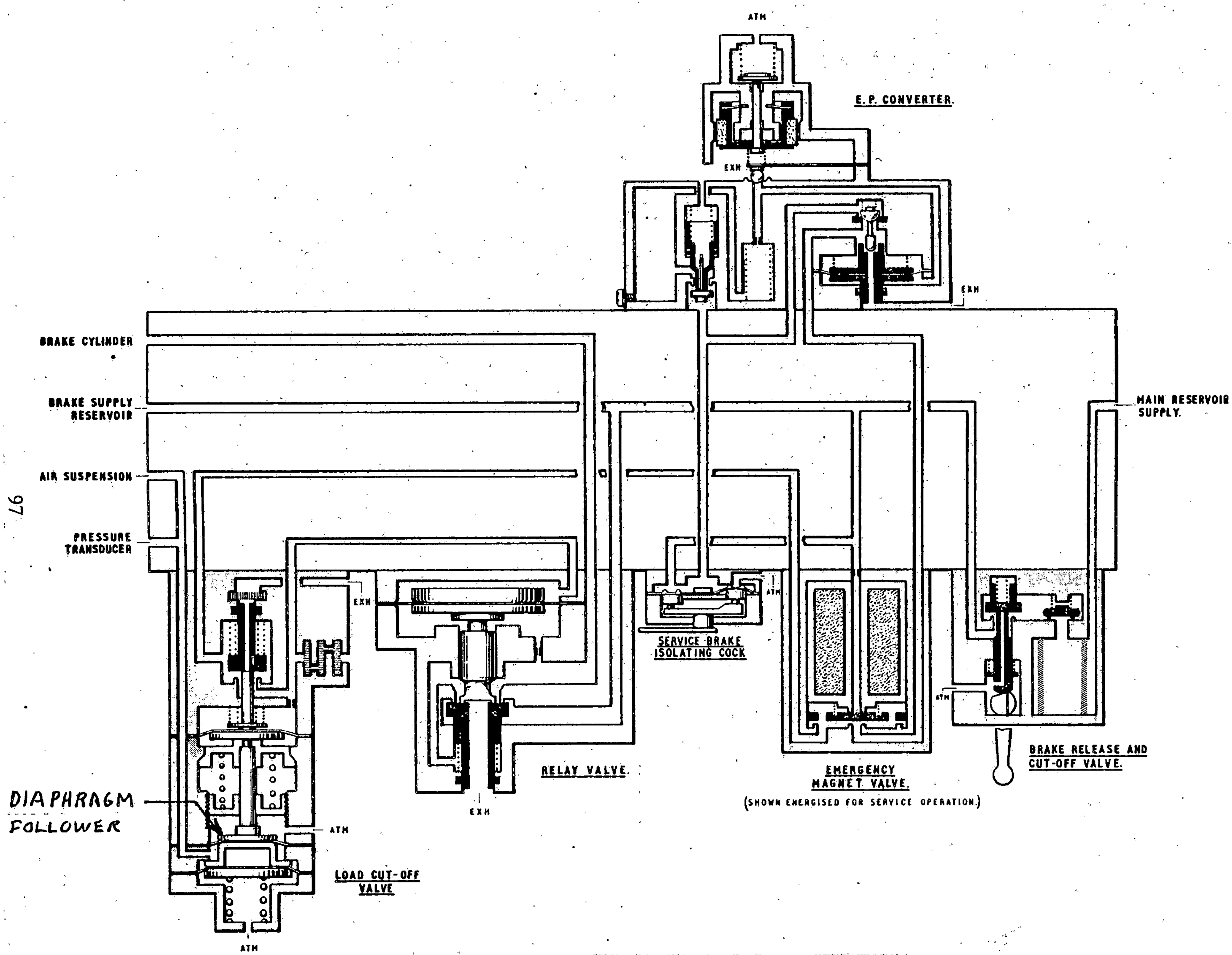


Figure 2–36. EP Converter

reservoir until the trailing compressor reached cutoff pressure. The resolution to this problem was to remove the spring and valve seat from the valve body of each of the check valves to permit the pressure switch on each compressor to directly sense the main reservoir pressure; therefore, both compressors are cut off simultaneously when the main reservoir reaches cutoff pressure. Figure 2-37 shows a portion of the pneumatic schematic to indicate the check valve (part no. P55-28) which has been modified by removing the spring and valve seat. The valve body was retained rather than expending the effort of replacing it with a union.

2.6 AUXILIARY ELECTRICAL POWER SYSTEM

2.6.1 System Description

The auxiliary electrical power system, AiResearch drawing 2017185, consists of alternator power supplies, the dc power supplies, ac and dc distribution systems, and associated components, circuits, and controls.

2.6.2 Low-Voltage Power Supply (LVPS)

The low-voltage power supply (41vdc), AiResearch drawing 2014299, consists of a transformer-rectifier primary supply with the ac input voltage supplied by one of the ESU alternators, a storage battery standby supply, and a battery charger power supply with control and protection equipment.

The low-voltage bus (41vdc) is supplied by the alternators via the transformer rectifier. When the low-voltage bus drops below the battery voltage due to loss of ac power, the battery is automatically connected to the bus. In normal operation, once the car is up and running, the storage battery is maintained by the battery charger power supply which operates from the low-voltage bus. In addition, a contactor isolates the battery from the low-voltage bus when the battery voltage drops below 24vdc to prevent damage to the battery. The contactor automatically restores power to the low-voltage bus when the battery has been recharged to 30vdc.

The only problems encountered with the low-voltage power supply during the Pueblo test program were with the battery charger section. Early in the test program it was noted that large transient voltage spikes were present on the output of the battery charger power transistors. The resultant modification relocated the power transistors to the heat sink, which resulted in a trouble-free low-voltage power supply for the rest of the test program.

There were two other minor problems associated with the low-voltage power supply. One required the input fuses to the low-voltage power supply logic to be changed from 1 amp to 2 amps (1 amp marginal) and the other required minor wiring changes to the battery charger. QSD relay to eliminate a double reset problem when bringing the car up on line.

Additional changes were made to the low-battery protection relay so that it would reconnect the battery to the bus when it has been recharged to 30vdc (originally 26vdc), and the battery field supply fuse was removed to isolate the low-voltage power supply from the 600vdc and the PDR's.

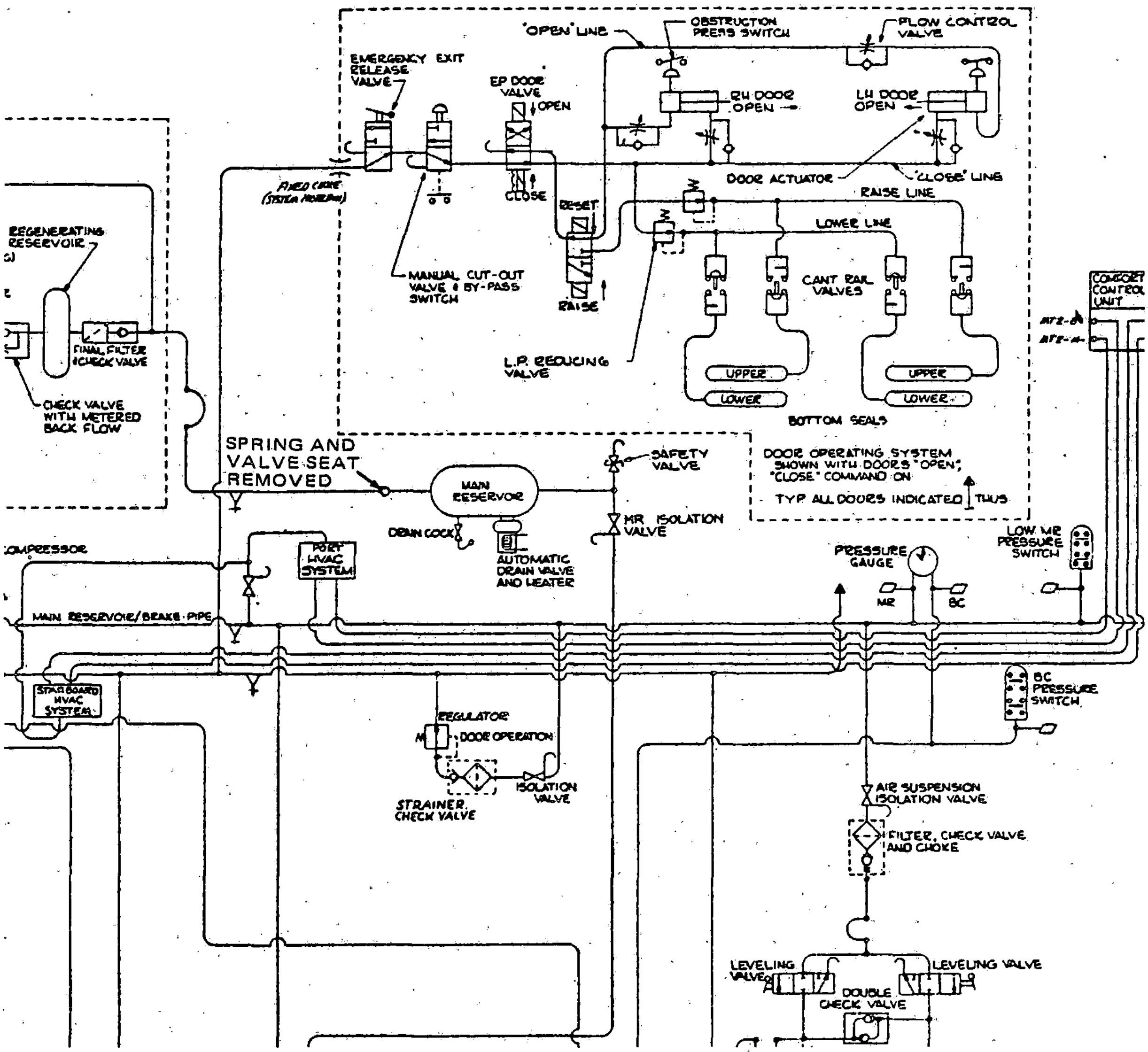


Figure 2–37. Pneumatic System Schematic

The low-voltage power supply as defined in AiResearch drawing 2014299, with the addition of the foregoing changes, represents the final configuration of the LVPS as delivered to UMTA at the completion of the test program.

2.6.3 Alternators (AC Power Supplies)

The ac power supplies on the ACT-1 vehicles consist of two alternators (1 per ESU) which provide power to drive the air-conditioning vent fans, low-voltage power supply, power conditioning, and propulsion system field power supplies (PDR'S). The alternators are mounted on the accessory drive of each flywheel.

The alternators used are Bendix 28B282-12 brushless ac generators which include a permanent magnet generator, rotating rectifier exciter, and current transformers to measure the main generator phase currents within the alternator package. The three-phase output of the unit supplies 220vac phase-to-phase at an average load of 42kva at frequencies of 280 through 382 Hz.

The mechanical drive to the alternators is provided by the ESU accessory gearbox alternator drive pad, which provides oil cooling and lubrication to the alternator and alternator drive spline from the ESU lubrication system.

Control and protection is provided by the alternator regulator circuits which voltage-regulate the output to a constant voltage of 220vac, line neutral by control of exciter field current. The permanent magnet generator supplies the field power of the exciter.

During the Pueblo test program three alternator failures were experienced. The first occurred on DOTX-5 during the preliminary test and adjustment phase of the program. While running on the transit test track, a propulsion shutdown was traced to an alternator (auxiliary generator no. 1) failure. The car was towed to the transit maintenance building and the alternator removed. Examination of the suspect alternator revealed that the fuseable links in the rotating rectifier exciter were open.

The defective alternator was sent to AiResearch for repair and the spare alternator was installed in the car. No reason for the alternator failure was identified. The car was run up with the new alternator and checked out properly.

The second and third alternator failures occurred during revenue service testing on DOTX-4. An investigation of an auxiliary generator trip showed no voltage output from alternator no. 2. The suspect alternator was removed and replaced with another unit. The car was run up in the transit maintenance building and after approximately 10 to 20 minutes of running, alternator no. 2 failed again. Upon examination of the ESU oil system, which showed severe metal particle contamination and a ruptured oil filter, it was decided to remove the ESU and ship it to AiResearch for a teardown inspection and cleaning of the lubrication system. The inspection showed an apparent bearing failure and a damaged alternator drive shaft, apparently caused by an unbalanced condition in the first alternator (Reference AiResearch report no. 78-15599, Flywheel Unit Failure Report).

There were no configuration changes to the original alternators (Bendix part no. 18B282-12) during the Pueblo test program and the final configuration was as delivered to Pueblo.

In order to expedite the end of the vehicle testing, it was necessary to install a lower power capability alternator in DOTX-5. (The two damaged units could not be repaired in time.) It was necessary to curtail the use of some of the subsystems but allowed the basic operation of the car. This allowed us to complete some of the two-car train testing at the end of the program. The nonstandard alternator was to be replaced by the transit maintenance crew at the test center as soon as the repaired units were available.

2.6.4 Alternator Voltage Regulator

The alternator regulators, AiResearch drawing 2017049, provides control and protection to the outputs of each of the ACT-1 vehicle alternators.

In order to prevent nuisance shutdowns of the propulsion system caused by voltage transients in the alternator regulator protection circuits, R36 was changed from 10k Ω to 6.8k Ω, which changed the logic trip point, and additional filtering was added by changing C3 from 10 μfd to 30 μfd. The alternator output voltages were adjusted to a high limit of approximately 240vac and a low limit of approximately 100vac. For the same reason, VR1 on the clamp circuit board was changed from an 18vdc Zener diode to a 27vdc Zener diode, which eliminated a race problem between the 220vac rise time and the 20v reference voltage.

The alternator regulator, AiResearch drawing 2017049, with these modifications represents the final configuration as presented to UMTA at the completion of the test program.

2.6.5 Low-Voltage Distribution Panel

The accessory control panel, AiResearch drawing 2017342-1, provides the control and protection of the various subsystems employed in the ACT-1 vehicles.

The only modification to the low-voltage distribution panel was to the PA circuit breaker, which controls the pantograph power and the Siemen's line breaker reset motor power. It was found, after a Siemen's reset motor burned up, that the PA breaker current rating was too high since it allowed the Siemen's reset motor to draw excessive current without tripping. The breaker was changed from a 15-amp unit to a 10-amp unit. In addition, the A5 assembly, AiResearch drawing 2018246, was modified by installing a jumper across R1 so that full bus voltage was applied to the Siemen's reset motor. This change allowed the reset motor to complete its cycle without hanging up and drawing excessive current.

The low-voltage distribution panel, AiResearch drawing 2017342-1, with the cited modifications represents the final configuration as presented to UMTA at the completion of the test program.

2.6.6 AC Distribution Panel

The ac distribution panel, AiResearch drawing 2017013, provides the control, protection, and distribution of the ac power required by vehicle subsystems such as the ventilation fans, flywheel motor and traction motor field PDR's, and low-voltage power supply.

The panel was modified during the test program to allow the air comfort indicator on the master control panel to light only when the ventilation fans turn off. Prior to the modification, the auxiliary generator warning light was being illuminated by the intentional turnoff of the ventilation fans when an ESU is operating below its minimum scheduled speed. The modification consisted of adding a wire from TB2-13 to Relay K6, pin 4.

The ac distribution panel with the cited modification represents the final configuration as presented to UMTA at the completion of the test program.

2.6.7 Battery

The ACT-1 railcars use a nickel-cadmium 24-cell Exide battery, AiResearch part no. 2017409-1, mounted on a rollout cradle that has provisions for full extension of the battery to a position completely outside the battery compartment.

The battery supplied has sufficient capacity to supply all loads normally connected to the battery voltage source which affect the safe operation of the train in the event of a 600v power failure or battery charger failure. The battery will also supply power for emergency ventilation, emergency lighting, and communications.

There were no changes or alterations to the battery and the final configuration presented to UMTA at the completion of the test program was the same as delivered to Pueblo by AiResearch.

2.6.8 Configuration Changes

A summary of the final configuration changes is shown in Table 2-XIII.

TABLE 2–XIII. FINAL CONFIGURATION CHANGES TO AUXILIARY ELECTRIC POWER SYSTEM OF DOTX-4 AND DOTX-5

Part No.	Component	Changed to
–	Toroid inductors	Added
–	Toroid inductors	Removed
2017199-1 2017197-1	Batt charger output transistors	Relocated to same heat sink
2017744-1 F4, F5, F6	1a fuse	2a fuse
2018180-1 K3	Batt charger QSD relay	Removed wire TB1-2 to K3-4 Added wires from TB1-2 to K3-15 and K3-16 to K3-4
–	Low batt voltage relay	Changed reset to 30 vdc
2017748-1 F4	Battery field fuse	Removed
2017049 R36	Logic trip point resistor 10k Ω	6.8k Ω
2017049 C3	Alternator reg filtering 10 μfd capacitor	30
2017049 VR1	Voltage clamp – 18vdc Zener	17vdc Zener
2017342-1	PA ckt breaker – 15a	10a
2018246	Current limit resistor – R1	Shorted out
2017013	Air comfort warning light control relay – K6	Added a wire from TB2-13 to K6, pin 4

2.7 HEATING, VENTILATING, AND AIR CONDITIONING (HVAC)

2.7.1 HVAC System Description

The HVAC system consists of two identical subsystems incorporated in each car. Each subsystem consists of an air-cycle turbocompressor powered by the energy storage unit through a fluid coupling, a heat exchanger pack including a recirculation fan, and interconnect ducting. Temperature controllers, sensors, duct and floor heaters, and ventilation fans are used to control the compartment temperature in the mode selected by comfort mode and control switches on the comfort control unit in the motorman's cab. The comfort mode switch allows selection of one of three modes: OFF, A/C, or LAYOVER. The comfort control switches allow selection of one of four modes: OFF, COOL, AUTO, or HEAT. Separate comfort control switches are provided for starboard (right side) and port (left side) HVAC systems.

Nominal supply voltages for the system are 41vdc for temperature control system components, 600vdc for duct and floor heaters, and 220vac, 267- to 382-Hz, 3-phase power to ventilation fans. Control circuit breakers in the low-voltage distribution panel in the motorman's cab are CC1 (starboard comfort control), CC2 (port comfort control), SF1 (starboard scavenge fan), SF2 (port scavenge fan), and VF (ventilation fan), and should be on for full system operation. In addition, the AC (air comfort) circuit breaker on the trainline breaker panel and the air comfort switch on the motorman's control panel must be on for system operation.

HVAC major components are listed in Table 2-XIV. Figures 2-38 and 2-39 show the general railcar location for these components.

2.7.1.1 HVAC Controls

The temperature control panels designated as TC1 and TC2 (see Figure 2-40) are located on the left cab bulkhead. Both units are identical, with the upper unit (TC1) providing temperature functions for the starboard (right side) HVAC unit and the lower unit (TC2) providing the same functions for the port (left side) HVAC unit. Controls on the front of each unit are provided for adjustment of the controlled temperature and humidity settings for units within the individual car. These functions are not trainlined.

The temperature control panel designated as TC3 is located below temperature control panels TC1 and TC2 on the left cab bulkhead as shown in Figure 2-39. This unit incorporates pneumatic-electric transducers which provide electrical inputs to temperature control panels TC1 and TC2 in response to pneumatic pressure inputs from sensors on the pneumatic panels of the HVAC units. This panel contains no controls or indicators on the front.

The comfort control unit, as shown in Figure 2-39, is located adjacent to the cab signal system equipment enclosure on the left side bulkhead. The air comfort ON/OFF switch located on the motorman's panel must be ON (in lead car) to provide power to this unit. Control switches

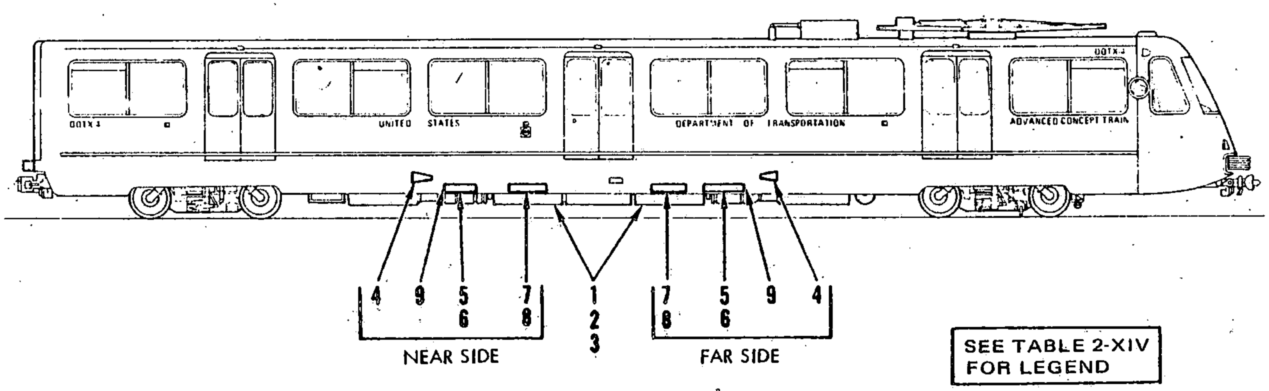


Figure 2–38. HVAC Major Component Location

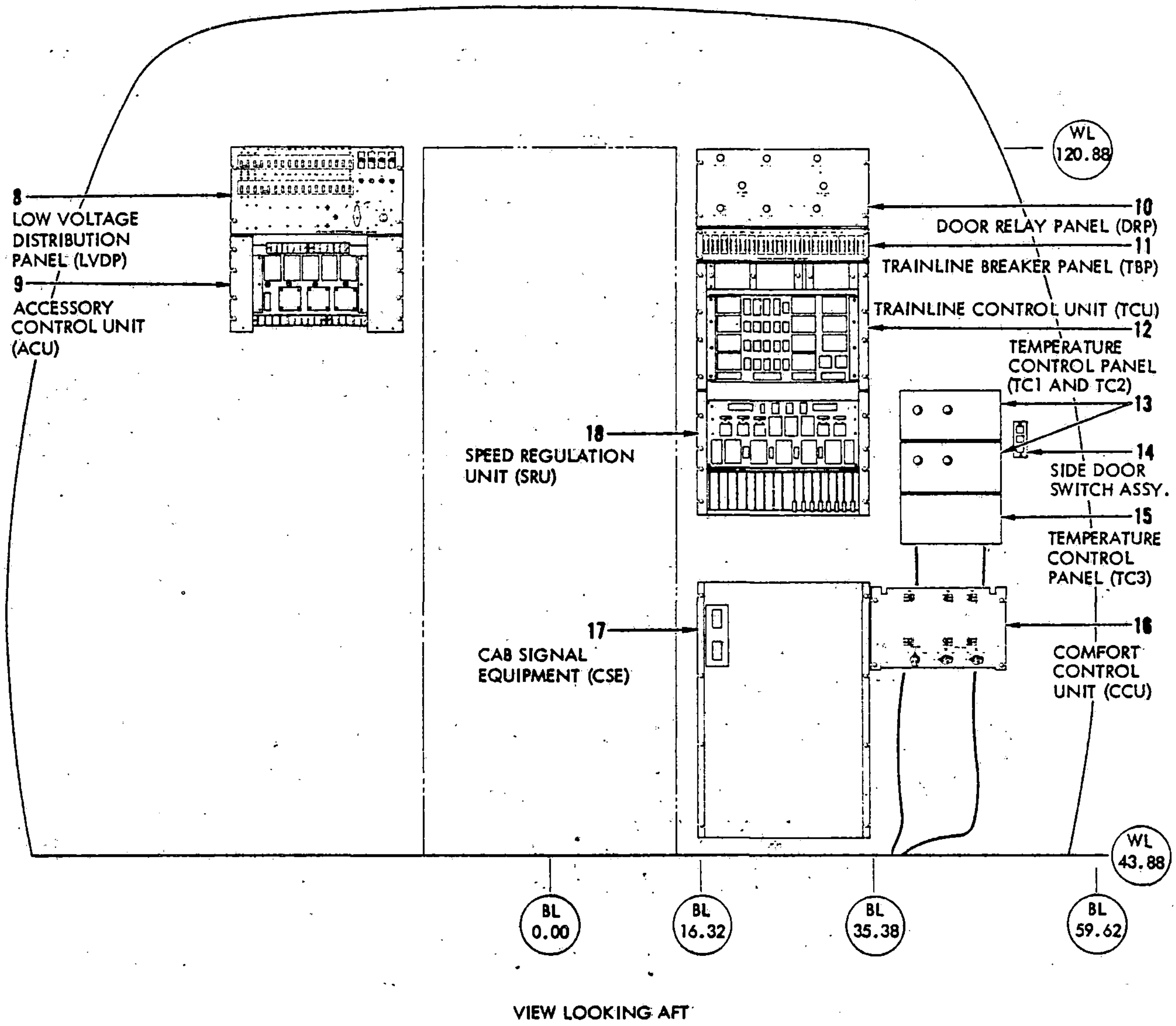


Figure 2–39. Motorman's Cab Equipment

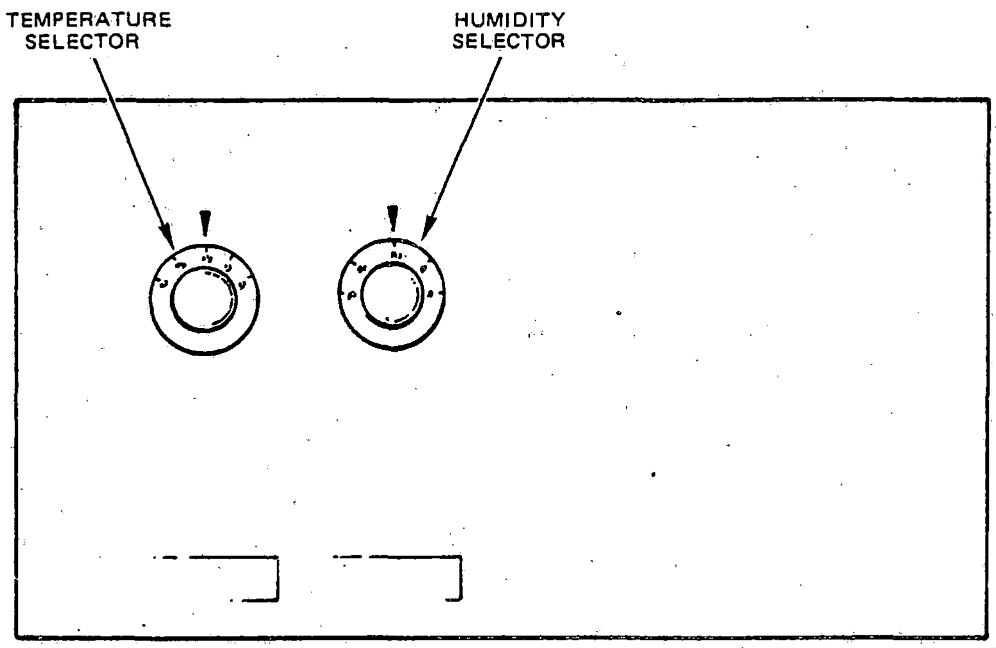


Figure 2–40. Temperature Control Panel

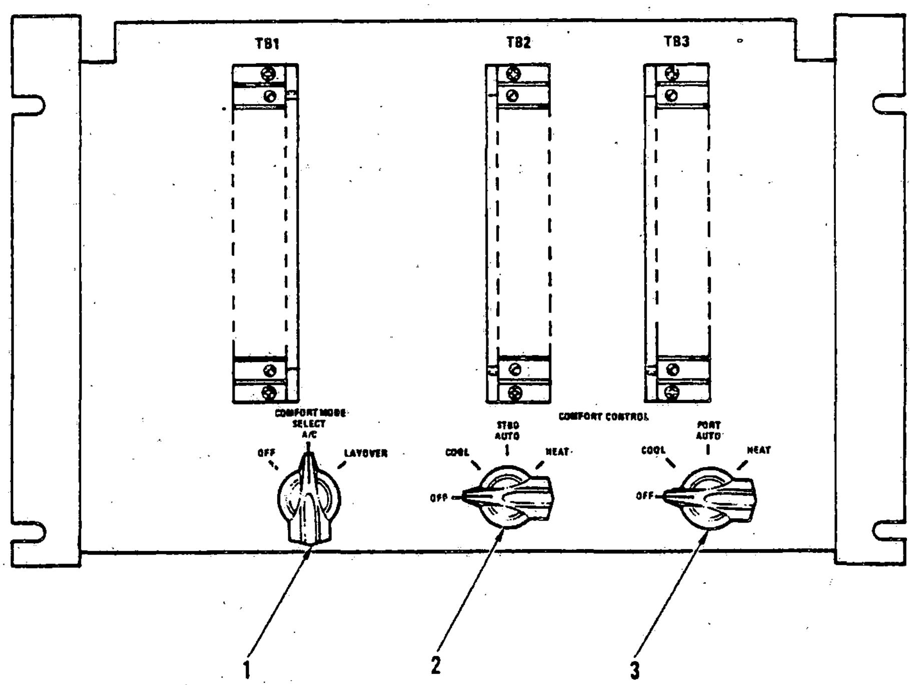


Figure 2–41. Comfort Control Unit

on the front of this unit are identified in Figure 2-41. Table 2–XV lists the panel marking, description, and function of these control switches.

TABLE 2–XIV. MAJOR COMPONENT INFORMATION

Item No.	Nomenclature	Desig	Part No.	Qty	Bay Loc	Schematic No.
	HVAC system	HVAC	–	–	–	2017419
1	Turbo-compressor	–	681261-1	2	6B/8B	–
2	Muffler	–	2200854-1	2	6B/8B	–
3	Bypass valve	–	2201185-1	2	6B/8B	–
4	Recirculation fan	VF	2201032-1	2	5A/9C	–
5	Inlet filter	–	2200857-1	2	5A/9C	–
6	Scavenge fan	SCAV	M2881R6A	2	5A/9C	–
7	Heater assembly	–	2200859-1	2	6A/8C	–
8	Temperature switch	TSC	AR2529KC	2	6A/8C	–
9	Temperature control	TC	LP97A1153	2	5A/9C	–
10.	Heater installation sidewall	–	2017186	1	Interior	–

TABLE XV. COMFORT CONTROL UNIT CONTROLS

Index No. (see Figure 2-18)	Legend/Panel Marking	Description	Function
1	COMFORT MODE	Switch	Permits selection of comfort mode either OFF, A/C, or LAYOVER
2	COMFORT CONTROL STBD	Switch	Permits selection of mode of control for starboard (right side) air comfort unit; Selectable modes are OFF, COOL, AUTO, or HEAT
3	COMFORT CONTROL PORT	Switch	Permits selection of mode of control for port (left side) air comfort unit; selectable modes are OFF, COOL, AUTO, or HEAT

2.7.1.2 System Operation (see Figures 2-42 and 2-43)

The air comfort system is designed for continuous control of heating, ventilating, and air conditioning. Heating is thermostatically controlled with blower fans operating in normal mode. When the ambient air rises above the desired setting, the ventilating cycle is exercised with the heat circuit off. With a rise in temperature above the capability of the ventilating system, air conditioning is energized. The activation of the entire system is arranged for trainline control from the motorman's cab.

2.7.1.3 Air-Conditioning Mode

The following procedure describes the system response to settings of the comfort control switch when the comfort mode select switch is in the A/C position.

a. Set both comfort control switches to COOL. System cooling turbines should be activated and cool air supplied through the air grills.

b. Set both comfort control switches to HEAT. System cooling turbines should be shut off and duct heaters activated, resulting in warm air being supplied through air grills.

c. Set both comfort control switches to AUTO. System will adopt heating, cooling, or ventilation cycle of operation to maintain car temperature within 3°F of temperature control thermostat setting. At temperatures more than 3°F above the setting, the turbocompressor turns on and provides cool air. At temperatures more than 3°F lower than the setting, the duct heaters turn on. At more than 4°F below the setting, floor heaters turn on.

2.7.1.4 Layover Mode

The following procedure describes the system response to setting the comfort mode select switch to LAYOVER. Both comfort control switches should be set to OFF in this mode.

a. Set both comfort control switches to OFF.

b. Set comfort mode select switch to LAYOVER. LAYOVER temperature control switch is set at 55°F and will activate the floor heaters if the compartment temperature falls below 50°F.

2.7.1.5 Cab Heating and Venting

Additional heating/demisting and venting components are provided in the motorman's cab. Control for the heater and ventilation fan are located on the motorman's control panel. Ducting from the cab heater directs hot air to the base of the motorman's windshield for demisting purposes. Also, the cab heater directs hot air to a cab floor outlet that can be manually

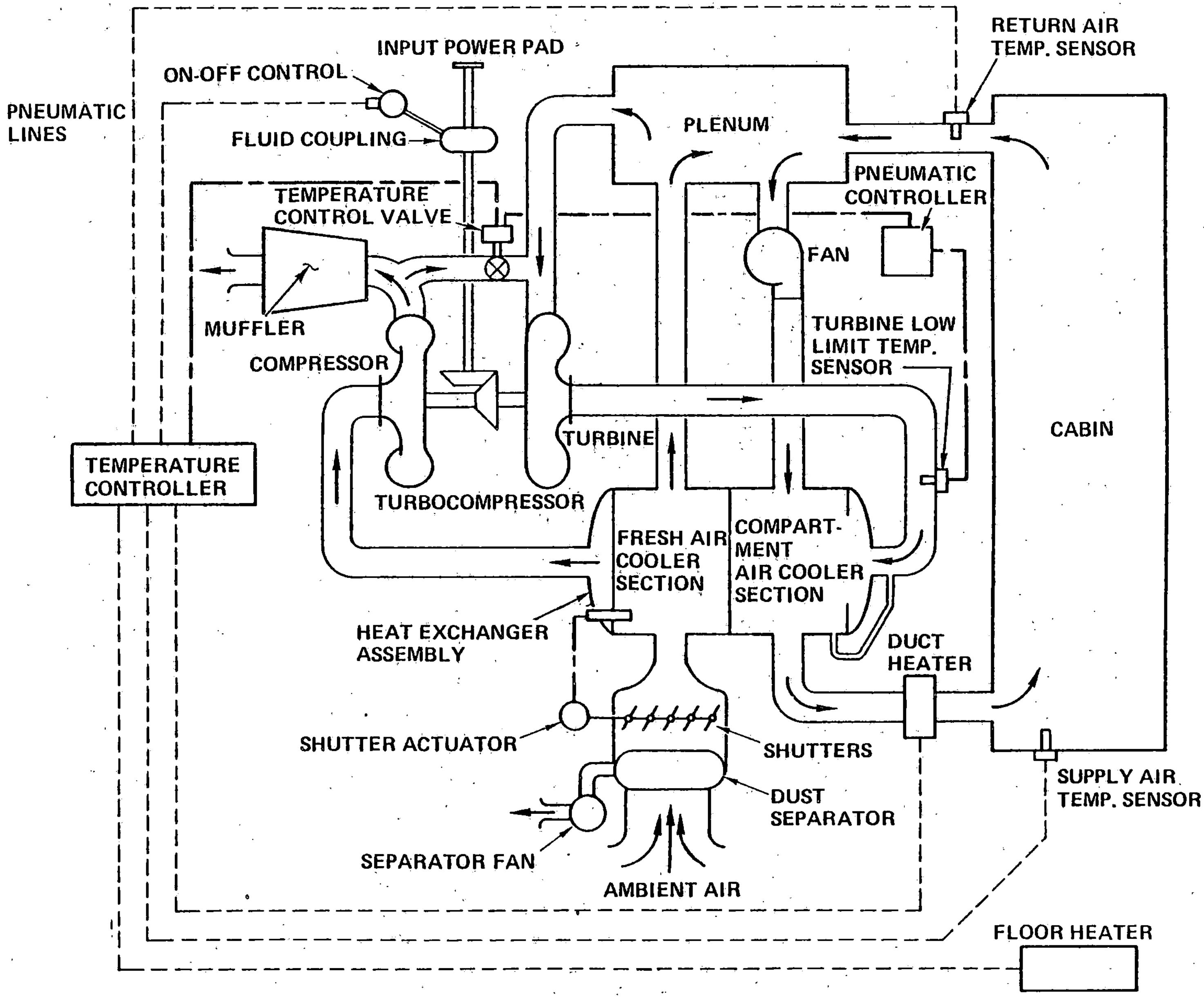


Figure 2–42. HVAC System Flow Diagram

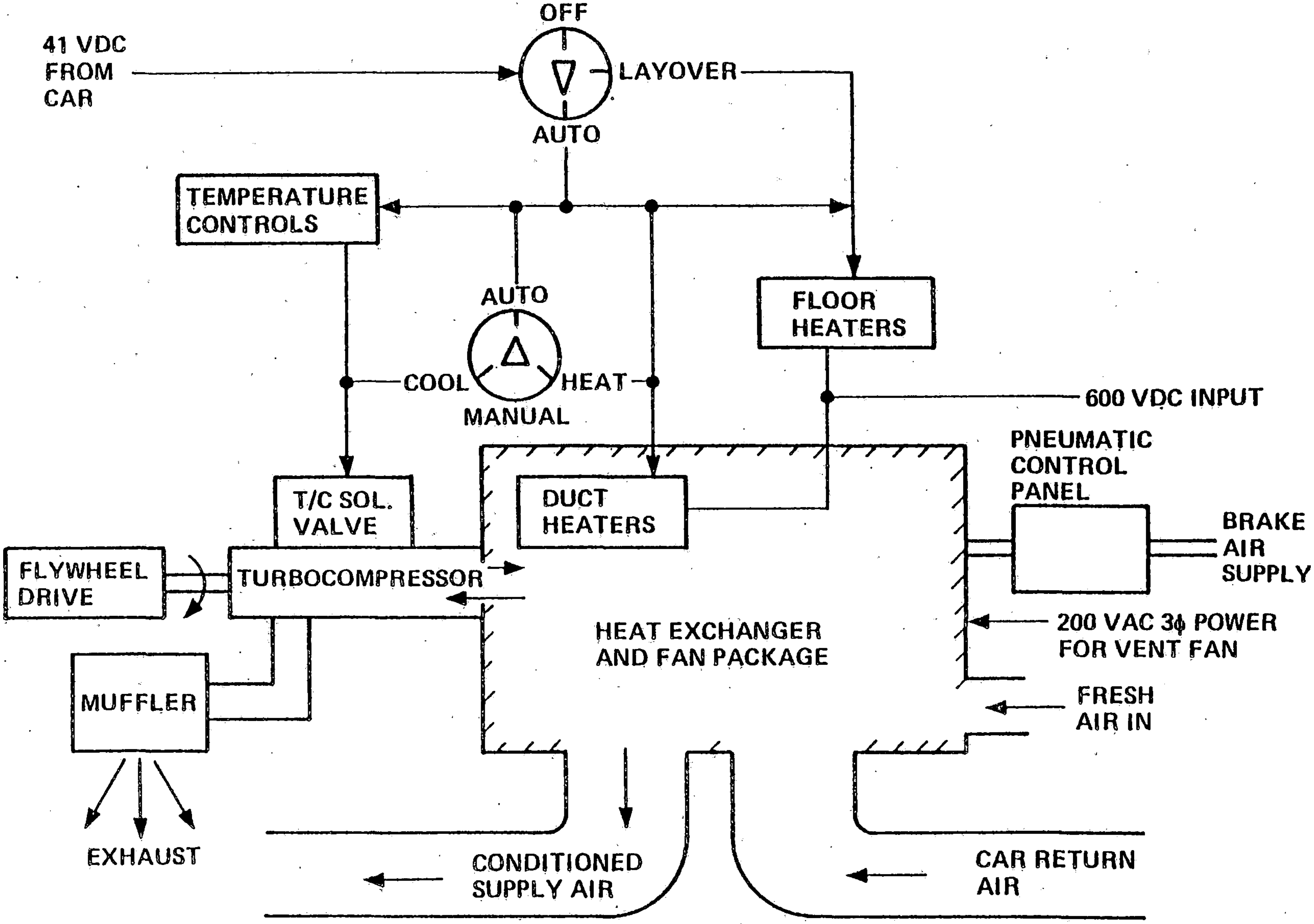


Figure 2–43. HVAC System Interface Diagram (Half System)

opened or closed. To operate the cab temperature components, the CA (control accessories) circuit breaker on the low-voltage distribution panel and the master key switch on the motorman's control panel must first be set to ON. Control switches on the motorman's control panel may then be operated as required to provide the required temperature conditions. These switches are identified by function and are as follows: CAB HEAT, CAB HEAT HI, CAB HEAT LOW, and CAB VENT.

2.7.2 Final Configuration

The ACT-1 HVAC system configuration when the vehicles were delivered to the Transportation Test Center is defined by the air conditioning system installation assembly drawing 200750 and the HVAC electrical/pneumatic system wiring diagram 2017419. The test program at TTC necessitated some HVAC system changes which are described below and summarized in Table 2-XVI to define the final HVAC configuration as delivered to UMTA upon completion of the TTC test program.

2.7.2.1 Heat Exchanger Bypass

The starboard HVAC pack on Car DOTX-5 exhibited a surging condition which could not be eliminated by fine-tuning of the anti-ice control. Blockage in the air ducting between the filtered-fresh-air inlet and the compressor was suspected, but a visual examination failed to reveal an obvious blockage. Manufacturing tolerances on the heat exchanger are a possible cause. The solution was to provide a supplemental air bypass around the obstruction with a 7/8-inch-inside-diameter hole from the fresh-air inlet downstream of the Donaldson filter to the compressor inlet duct. This modification was only required on the starboard pack on DOTX-5.

2.7.2.2 Return-Air Filters

The return-air filters (2017488-3) were removed from the compartment dividers in an attempt to improve air-conditioning efficiency. The filters, as shown in the sketch in Figure 2-44, have not been reinstalled in either car.

2.7.2.3 Heater Fuses

Surface temperatures up to 324°F were measured on the floor heater grills. The high temperatures were caused by heater elements with too high a rating per unit length. The installation of longer elements of the same total wattage would have required removing the sidewall panels and seats. Floor heaters were not considered necessary for the Pueblo test program and therefore new elements were not installed. Consequently, the floor heater fuses (F1 fuse on heater control assembly 2017248-1) were removed to prevent inadvertent operation of the floor heaters. The fuses are located in bays 4C and 10A.

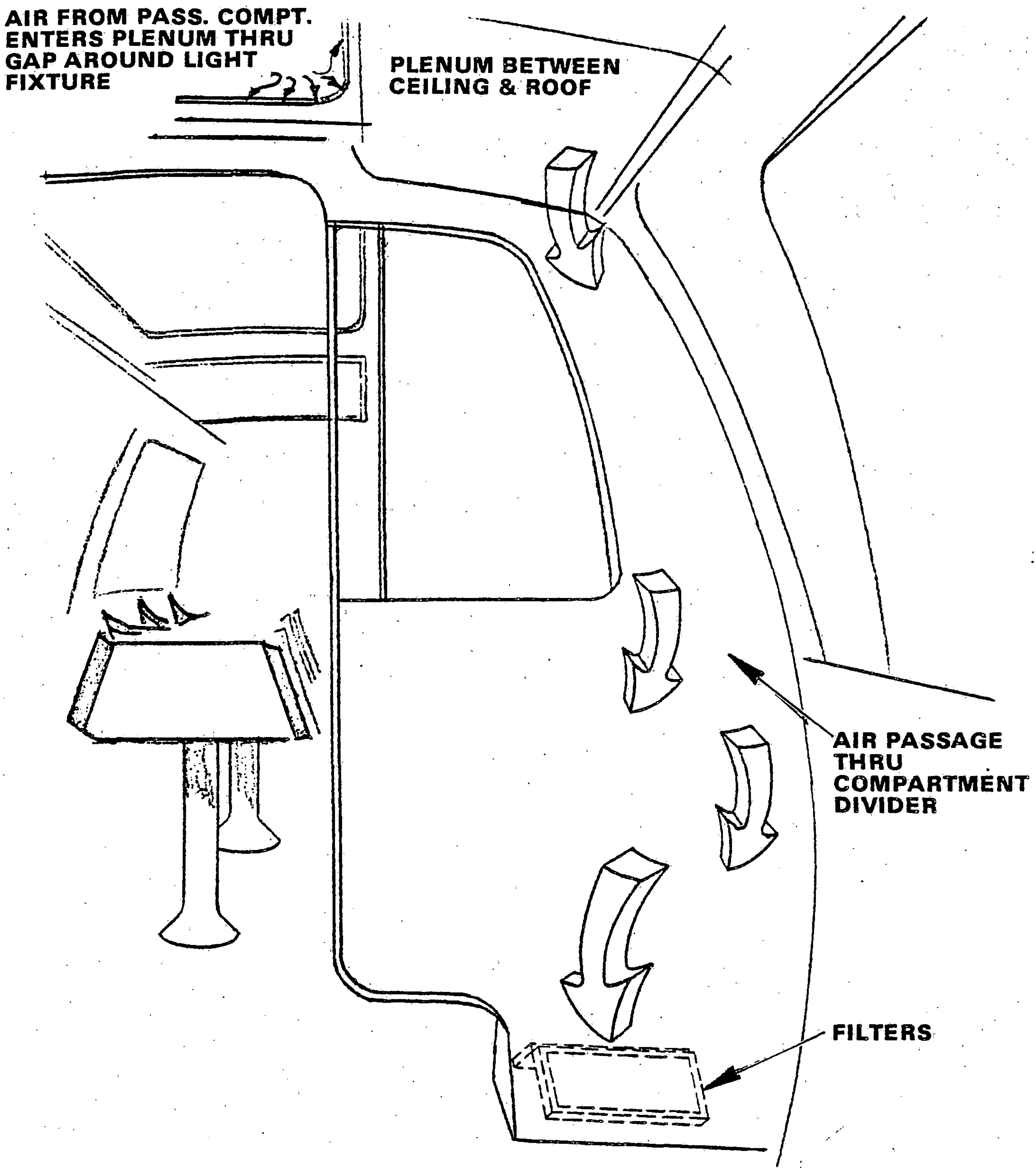


Figure 2–44. Return Air Distribution

2.7.2.4 Filter Bowl

The original design filter bowl on the HVAC control panel (2201056, item 14) was susceptible to frequent failure under the high thermal environment in the local area. These bowls have all been replaced by a higher-temperature-material bowl (Honeywell part number 14003428-001).

TABLE 2–XVI. FINAL CONFIGURATION CHANGES TO HVAC ON DOTX-4 AND DOTX-5

Original Part No.	Component	Changed to
2200636	Added 7/8-inch heat exchanger bypass	Starboard pack, DOTX-5 only
2017488-3	HVAC return-air filters	Removed
2017348-1	F1 fuse removed from panels in bays 4C and 10A to prevent floor heater operation	Fuses removed
2201056, Item 14	HVAC filter bowl material change	Honeywell part no. 14003428-001

2.8 COMMUNICATION SYSTEM

The ACT-1 communication system, AiReserarch drawing 2017184, consists of an automatic station announce system, a closed-circuit television system, and four audio subsystems. The systems interface via the communication electronic unit and are controlled by switches on the motorman's console.

2.8.1 Closed-Circuit Television (CCTV)

The closed-circuit television system used in each of the ACT-1 vehicles consists essentially of four cameras, two monitors, and their associated controls. Two of the cameras are diagonally mounted inside the railcar for interior surveillance. The other two cameras are mounted in the cab exterior wall, one on each side, facing rearward to provide train side and platform surveillance. Controls on the motorman's panel are used to select the mode of display presented on the monitors. As selected, the monitors may display the two interior cameras in one railcar simultaneously, or sequence from railcar to railcar, or either exterior side of the railcars.

The CCTV system was not formally tested at Pueblo, but was functionally checked almost every time one of the cars ran during the test program. During most of the single-car testing, the CCTV system was used in the daily operation of the train for crew surveillance and test control. The trainline functions of the CCTV system were never checked out due to the limited two-car train testing. The single-car system performed well during the test program and there were no configuration changes. The CCTV system represented in AiResearch drawing 2017184 was delivered to UMTA at the completion of the test program.

2.8.2 Public Address System

The public address system consists of 12 speakers per railcar and a monitoring speaker in the motorman's cab. Power for these speakers is supplied by the main audio unit (MAU), AiResearch part no. 5120-0710. The public address system can be used for automatic announcements of station stops by the station display and announce systems, motorman's announcements through the handset of the motorman's control panel, announcements by way of wayside radio transmitters via the train radio, and audio tones in response to the crew buzzer switch.

Although no formal test of the system was conducted, the system was used almost constantly for test crew announcements, test instructions, and as a troubleshooting aide during the on-track testing at Pueblo.

There were no configuration changes to the public address system and the final configuration delivered to UMTA at the completion of the test program was as delivered to Pueblo by AiResearch.

2.8.3 Railcar-to-Wayside Radio

The railcar-to-wayside radio system uses a train radio unit designed for two-way radio communication between wayside radio installations and the railcars.

Control elements for the radio are located on the motorman's control panel which employs the motorman's handset for transmitting from the railcar. Power for the system is obtained directly from the low-voltage bus, thus isolating the radio from the rest of the communication system.

The radio delivered to Pueblo with DOTX-5 was removed at the beginning of the test program for power supply modifications and test-center-frequency crystal installation. Due to a problem obtaining the proper crystals for this radio, it was decided not to use the train radio for on-site communications. Communication was provided by handheld walkie-talkies between the test cars, other members of the test team, and the operations control center at the transportation test center. DOTX-4 was delivered to Pueblo without a train radio since the intent was to switch the one radio from car to car during the test program.

There were no modifications made to the train radio or the associated car circuitry, with the exception of insulating the radio input/output connectors from the car body.

The railcar-to-wayside radio system, represented in AiResearch drawing 2017184, represents the final configuration delivered to UMTA at the completion of the test program.

2.8.4 Station Announce and Display

The automatic station announce and display system consists of alphanumeric display units for visual presentation of upcoming station stops and an input to the public address system which announces the next station stop. The signals for the display units and the input to the public address system are from a prerecorded tape which is inserted in the tape transport unit, located in the communications equipment console in the left front of the cab. Controls for operating the tape transport are provided on the motorman's control panel.

The station announce and display system was never used during the Pueblo test program, nor was any formal testing of the equipment attempted. The tape transport unit was used to play music through the public address system during some of the demonstration rides.

There were no changes or modifications to the system and the final configuration delivered to UMTA at the completion of the test program was as delivered to Pueblo by AiResearch.

3.0 PRELIMINARY TEST AND ADJUSTMENT

Following shipment and reassembly of the ACT-1 cars at the Transportation Test Center, a series of preliminary tests and adjustments was conducted to verify proper operation of the various subsystems and to optimize performance parameters prior to conducting the engineering and acceptance tests.

The preliminary test and adjustment phase of the program entailed a much greater effort than had originally been planned due to significant hardware problems such as ESU failures, motor commutation, brake overtemperatures, and control system sequencing. Initial efforts were directed toward adjusting the electronic control unit (ECU) to provide proper sequencing of events through all modes of operation, while at the same time minimizing dead time between events. This was followed by iteration of ECU component values to optimize vehicle acceleration and braking performance. Many of the performance parameters are interrelated and an improvement in one parameter may have an adverse effect on another parameter.

A summary of the preliminary tests and adjustments follows.

3.1 WEIGHTS

3.1.1 Summary

The ACT-1 car weight grew rather significantly from a program concept weight of 76,000 pounds in 1973 to an actual weight of approximately 92,000 pounds. The wheel load distribution and equalization with the airbags inflated is within the revised specification requirements. The distribution and equalization loads with deflated airbags exceeded the specification but still represents a safe condition.

3.1.2 AW0 Weight

As a result of the original ACT-1 proposal evaluation, it was established that a growth from the proposal estimated weight could be expected. The estimated weight growth history is shown in Figure 3-1. The final weight breakdown summary is shown in Table 3-I. The final actual weight of the high-density car (DOTX-5) was 91,711 pounds as determined by summing the individual wheel weights from the wheel load distribution test.

At an empty weight of 91,711 pounds, the ACT-1 cars do not compare favorably with other recent 75-foot aluminum or stainless-steel cars, and the overweight adversely affects both performance and the economic benefits provided by the energy storage units. A comparison shown in Table 3-II shows that when the weights for energy storage, energy attenuation, and other features incorporated into the ACT-1 cars are deleted, the weight is reduced to a more acceptable level.

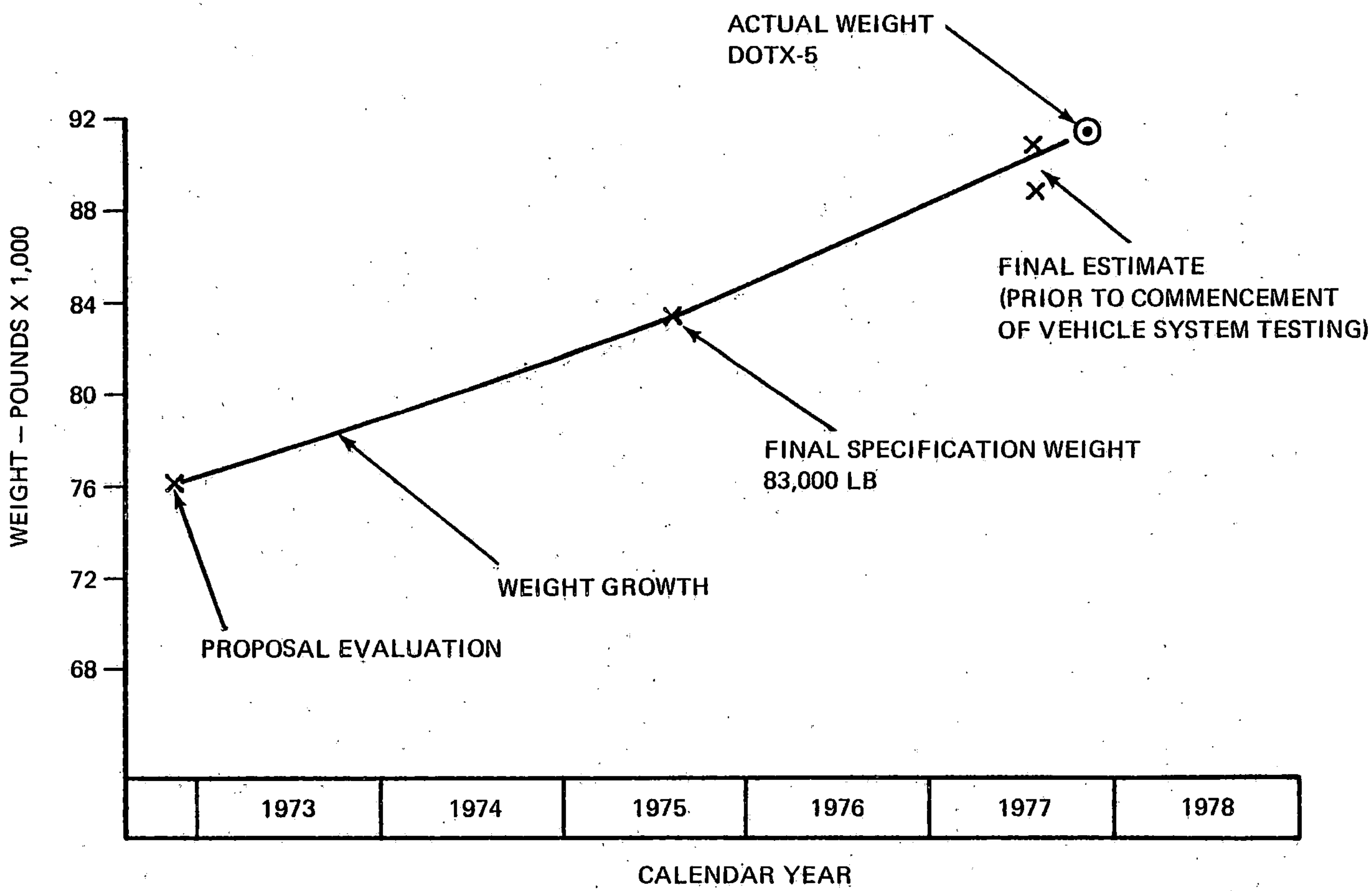


Figure 3–1. ACT-1 Weight Growth History

TABLE 3–I. ACT-1 WEIGHT BREAKDOWN SUMMARY
(FINAL ASSESSMENT BY GARRETT AIRESEARCH 5/1/77)

	WEIGHT (LBS)	% ACTUAL
CARBODY	((40,991))	
PRIMARY STRUCTURE	(20,273)	(100)
ROOF	1,238	
SIDE FRAMING	7,929	
UNDERFRAME	6,662	
CAB STRUCTURE & ANTI-CLIMBER	1,004	
ENERGY ATTEN. "A" END	1,394	
ENERGY ATTEN. "B" END	1,296	
"B" END STRUCTURE & ANTI-CLIMBER	750	
SECONDARY STRUCTURE	(13,050)	(83)
FLOOR PANELS	1,896	
WINDOWS & GLAZING	2,843	
DOORS & TRACKS	1,692	
SIDE PANELS & SKIRTS	1,466	
CAB END CLOSURES	1,181	
COUPLERS	1,550	
BELLY PANS & A/C DUCTS	—	
EQUIPMENT BRACKETRY	1,349	
SIDE BEARERS	800	
CENTER PIN ASSEMBLY	123	
PAINT, TRIM, AND SEALER	150	
INTERIOR	(7,668)	(35)
FLOOR COVERING	2,514	
TRIM & PANELING	2,442	
SEATS (LOW DENSITY)	2,712	
WINDSCREENS	—	
TRUCKS	((25,867))	(90)
NON-ROTATING PARTS	(12,376)	
MOTOR MOUNTS	564	
AXLE HOUSING	2,010	
CALIPER	2,120	
RUBBER SLEEVES	244	
FRAME & TRANSOM	3,270	
AIR SPRINGS	446	
TORSION BARS & LINKAGE	306	
SHOCK ABSORBERS	114	
SUSPENSION ADAPTER	1,830	
RADIUS RODS	92	
SPIDER WELDMENT	300	
MISCELLANEOUS	1,080	
ROTATING	(13,576)	
MOTOR	5,990	
COUPLING	300	
AXLE SHAFT	948	
CARRIER ASSEMBLY	1,604	
WHEELS	4,562	
TRUCK BEARINGS	—	
OIL (172 PINTS)	172	
EQUIPMENT	((24,008))	
PROPULSION	(13,988)	(96)
PROP. CONTROL	1,590	
INDUCTOR	775	
MOTOR, ESU	5,869	
FLYWHEEL & GEARBOX	5,454	
FORCED AIR COOLING	300	
AIR COMFORT SYSTEM	(1,940)	(80)
AIR COMFORT	1,765	
HEATERS	25	
HEATER CONTACTORS	150	
AUXILIARY POWER & CONTROLS	(5,719)	(24)
AUXILIARY POWER	1,725	
WIRING & RACEWAYS	3,994	
PNEUMATIC SYSTEM	(969)	(53)
PNEUMATIC SYSTEM	891	
COUPLER CONTROL	48	
AIRLINE CONTROL	18	
ROTARY SWITCH	12	
GEAR	—	
HYDRAULIC PUMP	—	
MISCELLANEOUS	(1,392)	(20)
COMMUNICATIONS	260	
DESTINATION SIGNS	195	
ATC SYSTEMS	480	
MOTORMAN'S EQUIPMENT	47	
LIGHTING	410	
TOTAL EMPTY WEIGHT (LOW DENSITY CONFIG.)	90,866	82%
TOTAL EMPTY WEIGHT (HIGH DENSITY CONFIG.)	89,336	83%

TABLE 3–II. COMPARISON OF 75-FOOT-CAR EMPTY (AW0) WEIGHTS

		Weight (lb)
SOAC	(stainless steel)	83,831
NYCTA R44	(stainless steel)	81,000
Toronto Subway H4	(aluminum)	65,000
BART	(aluminum)	61,000
WMATA (Spec)	(aluminum)	72,000
ACT-1		91,711
Removing features unique to ACT-1 cars:		
Energy attenuation Propulsion/ESU system delta Non-state-of-the-art features (double-glazing, etc)		– 14,604
Adjusted ACT-1 weight		77,107

Some success in weight reduction has been achieved. The total weight of the truck assemblies at 26,516 pounds per car set represents a saving of 1,836 pounds, or 6.5 percent under the state-of-the-art car truck assemblies.

3.1.3 Wheel Load Distribution

The wheel load distribution test determined the static distribution of load supported by each wheel in a level condition. The test was performed on an instrumented empty car (DOTX-5) in the ready-to-run configuration. Wheel loads were measured employing individual load cells (Boeing electronic weighing kit) together with suitable jack and special adapters placed adjacent to the wheels. Both trucks were weighed in the Transit Maintenance Building (TMB). Testing was accomplished in two suspension configurations: 1) airsprings deflated, and 2) airsprings inflated.

Large variation in wheel support loads result in unsymmetrical wheel tread wear per axle and lateral wheel creep forces that cause flange wear. Both lead to premature wheel replacement and are therefore undesirable.

The ACT-1 car design has a uniform distribution of equipment. However, the secondary suspension airbags are located offcenter, which caused a wheel load variation in excess of the original specification requirement. The specification was revised (SCCR1609) to a maximum of 13 percent at all weights.

With the suspension system inflated (normal configuration), the test results shown in Figure 3-2 indicate the wheel loads are within 12.9 percent. With the airsprings deflated, the test results shown in Figure 3-3 indicate wheel load variations up to 23.9 percent.

Although this load is beyond the specification requirement, it does not represent an unsafe condition for short-term operation.

3.1.4 Wheel Equalization Loads

It is a desirable characteristic of any truck frame and suspension design that, while in operation, should one wheel be caused to rise over a track irregularity, the system be flexible enough not to cause a redistribution of wheel loads that could represent an unsafe condition, i.e., one wheel load being reduced to zero.

Paragraph 11.4.1 (Equalization) of the specification states that equalization shall be accomplished through the truck frame, independent of the primary suspension. With car weights AW0 to AW3 on level tangent track, lifting any wheel 2.0 inches shall result in load changes on any other wheel not greater than 20 percent. This requirement applies for airsprings inflated or deflated.

Test results from the wheel load distribution test were used for level truck zeros. Jack limitations prevented lifting a wheel beyond 1.5 to 1.6 inches and results at 2.0-inch lift were extrapolated. For all tests the heaviest wheel (level truck) was lifted. Therefore, a different wheel was lifted during suspension-inflated and -deflated tests.

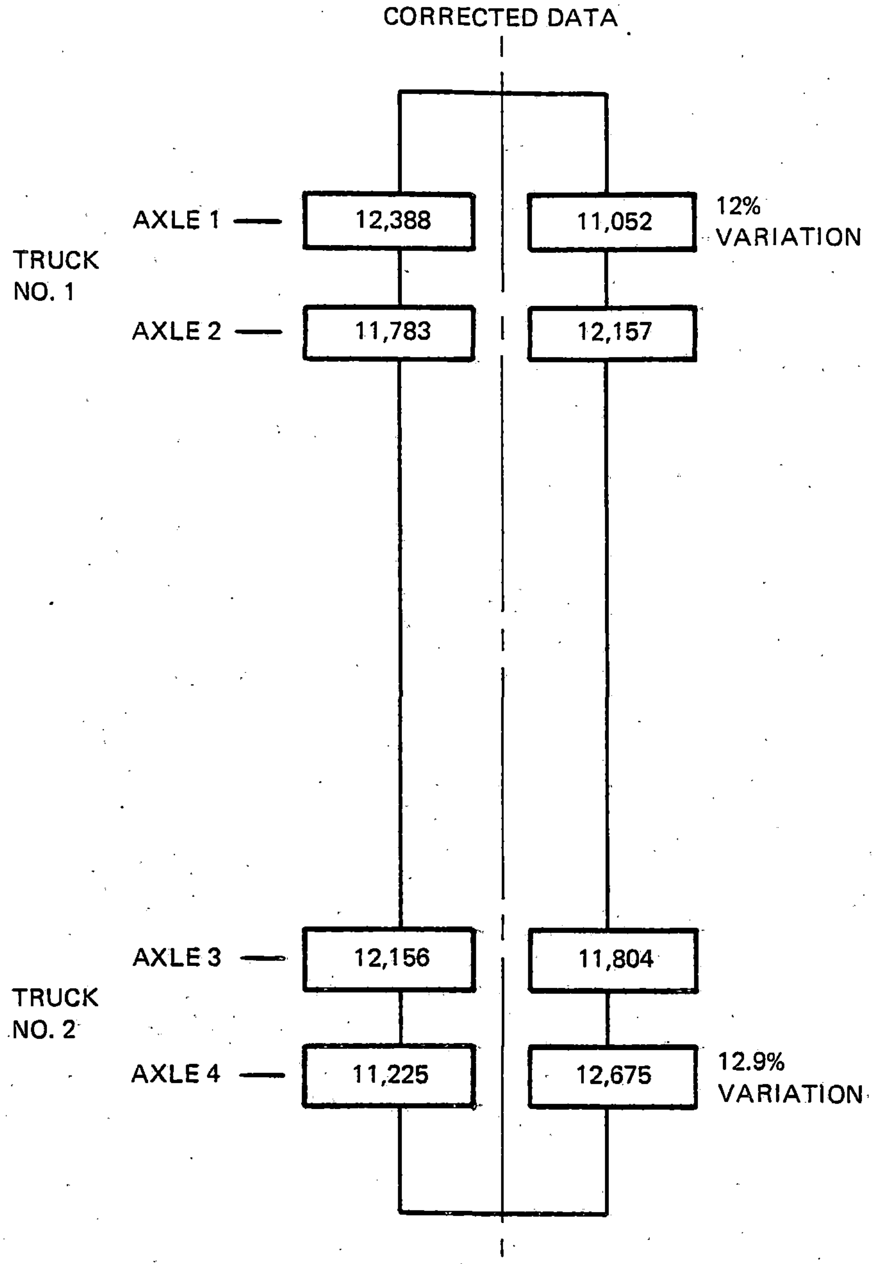
The test results shown in Figure 3-4 indicate a maximum load reduction of 13.9 percent with the airsprings inflated and 22.9 percent with the airsprings deflated, the latter slightly exceeding the specification requirement of 20 percent.

3.2 ESU STARTUP AND SHUTDOWN

The operation of the ESU was verified by starting it up to idle and idle boost speeds and then shutting it down. The operation was checked for each car individually and for the two-car train. ESU startups were also performed under low- and high-line-voltage conditions. The ESU characteristics measured during these tests are summarized in Table 3-III. Time histories for startups to idle and idle boost speeds and a shutdown from idle speed are shown in Figures 3-5 through 3-7.

With 600 volts line voltage, the time required from startup to idle speed (73 percent) is approximately 3.5 minutes, and the time required from start-up to idle boost speed (88 percent) is approximately 4.0 minutes. The time required to shut down from idle speed is 6.8 minutes. The energy consumed in obtaining idle and idle boost speed is 15.4 to 16.9 kw-hr and 18.7 to 21.0 kw-hr, respectively. The power required to maintain idle and idle boost speed is approximately 40 and 50 kw, respectively.

TEST CONDITION: EMPTY WEIGHT (AWO PLUS INSTRUMENTATION), AIR SPRINGS INFLATED

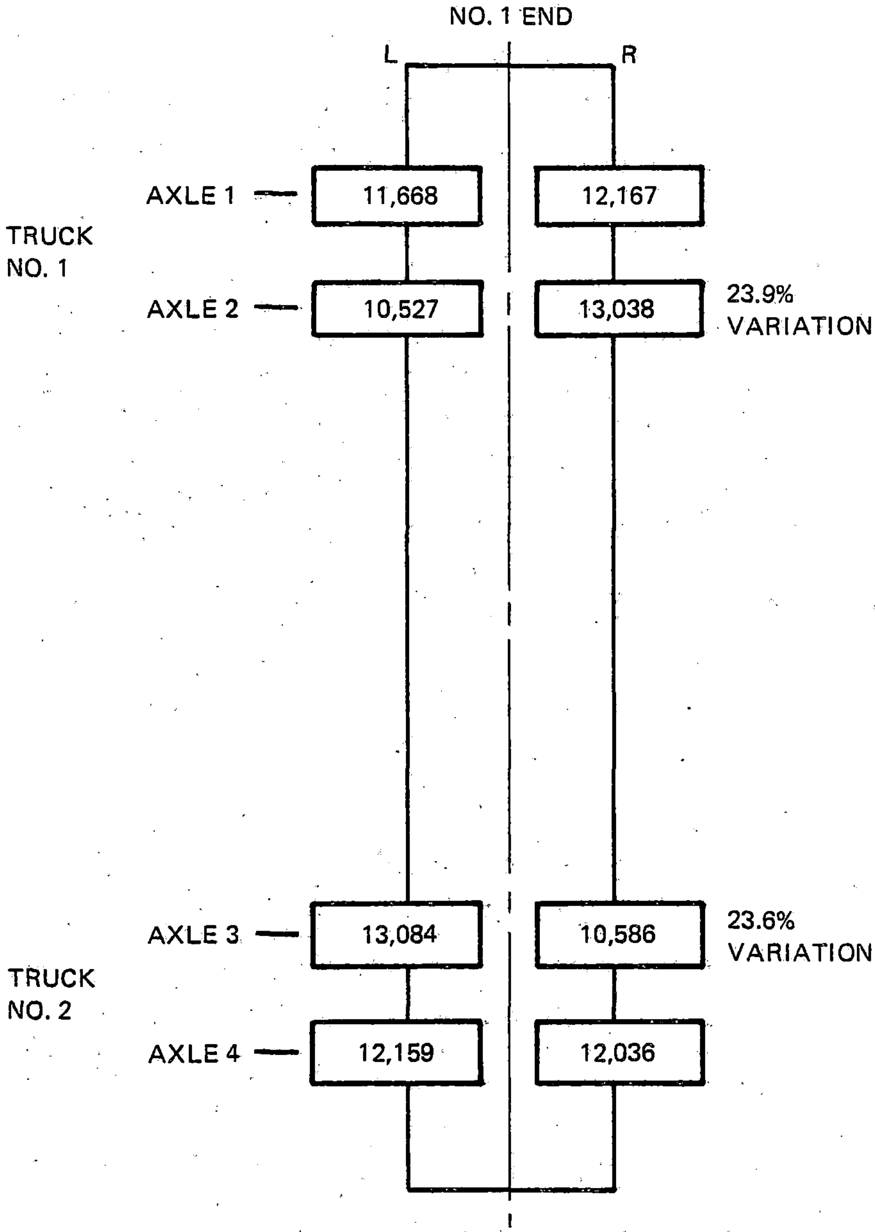


TEST RESULTS		SPECIFICATION REQUIREMENT
MAXIMUM LOAD VARIATION	1,450 LB (12.9%)	WHEEL LOAD VARIATION SHALL NOT EXCEED 13 PERCENT AT WEIGHTS UP TO AW3
TRUCK NO. AXLE NO.	2 4	

Figure 3–2. ACT-1 Wheel Load Distribution Test Data

TEST CONDITION: EMPTY WEIGHT (AWO PLUS INSTRUMENTATION), AIR SPRINGS DEFLATED, MARSHMALLOW SPRINGS SHIMMED 1/2 IN. UP PER SK-JLM-001

CORRECTED DATA



TEST RESULTS	
MAXIMUM LOAD VARIATION	2,511 LB (23.9%)
TRUCK NO. AXLE NO.	1 2

Figure 3–3. ACT-1 Wheel Load Distribution Test Data

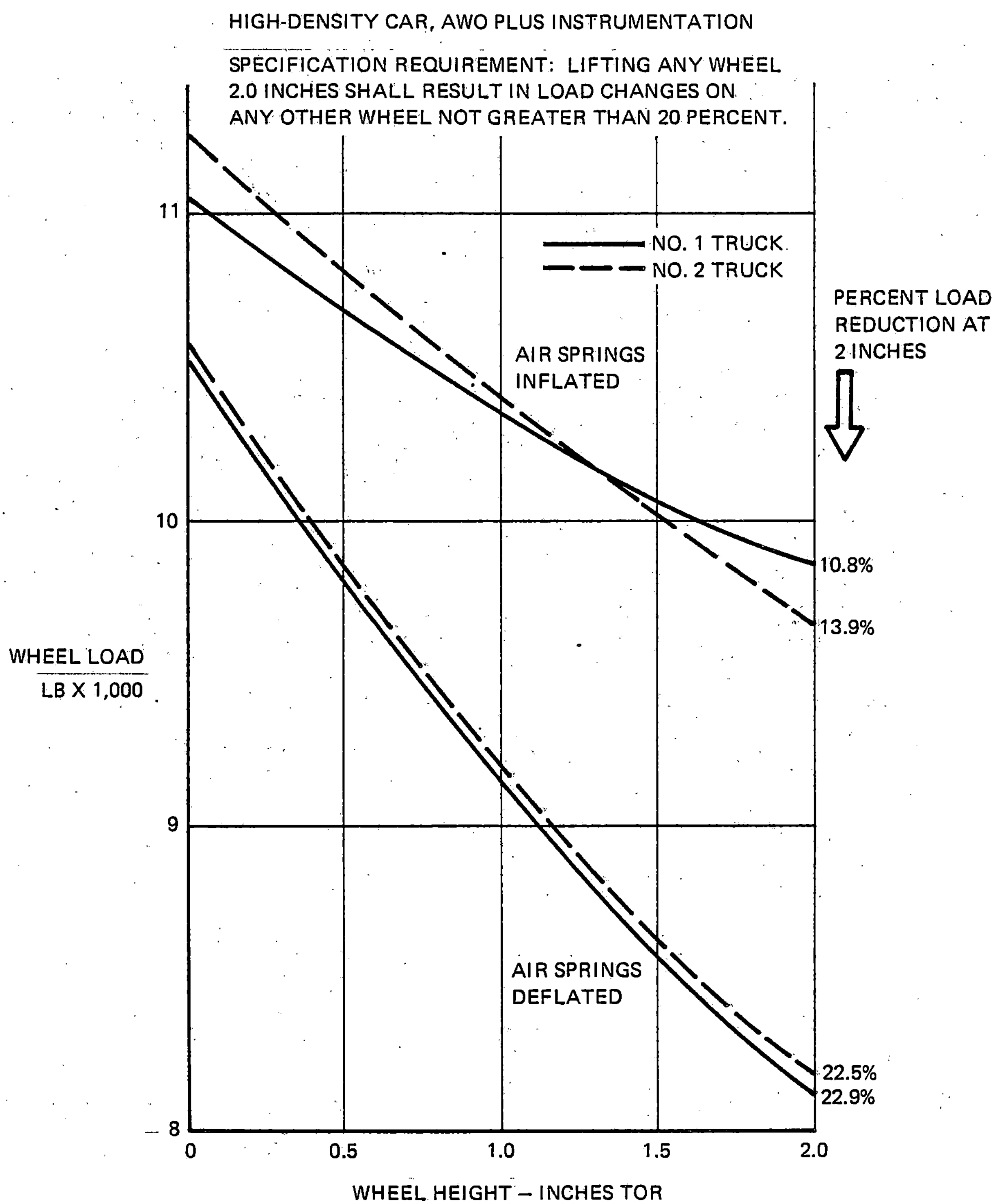


Figure 3–4. Wheel Equalization Test Results

TABLE 3–III. ESU STARTUP/SHUTDOWN CHARACTERISTICS

Condition	Car	Record No.	Idle Boost	Time (minutes)	Energy Consumed	ESU Speed	Average Line Voltage
Startup	DOTX-5	779	Off	3.2	15.7	73.2	620
Startup, low voltage	DOTX-5	787	Off	3.6	15.6	72.4	574
Startup, high voltage	DOTX-5	786	Off	2.5	15.4	72.8	682
Startup	DOTX-5	780	On	3.6	18.7	87.6	620
Startup	DOTX-4	567	On	3.6	19.4	88.9	640
Shutdown	DOTX-4	568	On	11.01	1.7	87.3	701
Startup, 2-car train	DOTX-4, -5	894	Off	3.7	16.9	72.9	615
Startup, 2-car train	DOTX-4, -5	896	On	4.1	21.0	87.8	606
Shutdown, 2-car train	DOTX-4, -5	895	Off	6.8	1.2	73.0	663

NOTES:
1. ESU speed was driven down to 41 percent. It then had to coast down from 41 to 28 percent. It was driven down from 28 percent. This problem was corrected, but ESU shutdown data was not subsequently taken for DOTX-4.
2. Stationary car
3. ACT-1 preliminary test and adjustments, DOT TTC, Pueblo, Colorado

NOTES:
1. STATIONARY CAR
2. ESU IDLE BOOST OFF
3. ACT-1 PRELIMINARY TEST AND ADJUSTMENT, DOT-TTC, PUEBLO, COLORADO

DOTX-5 RECORD: 779

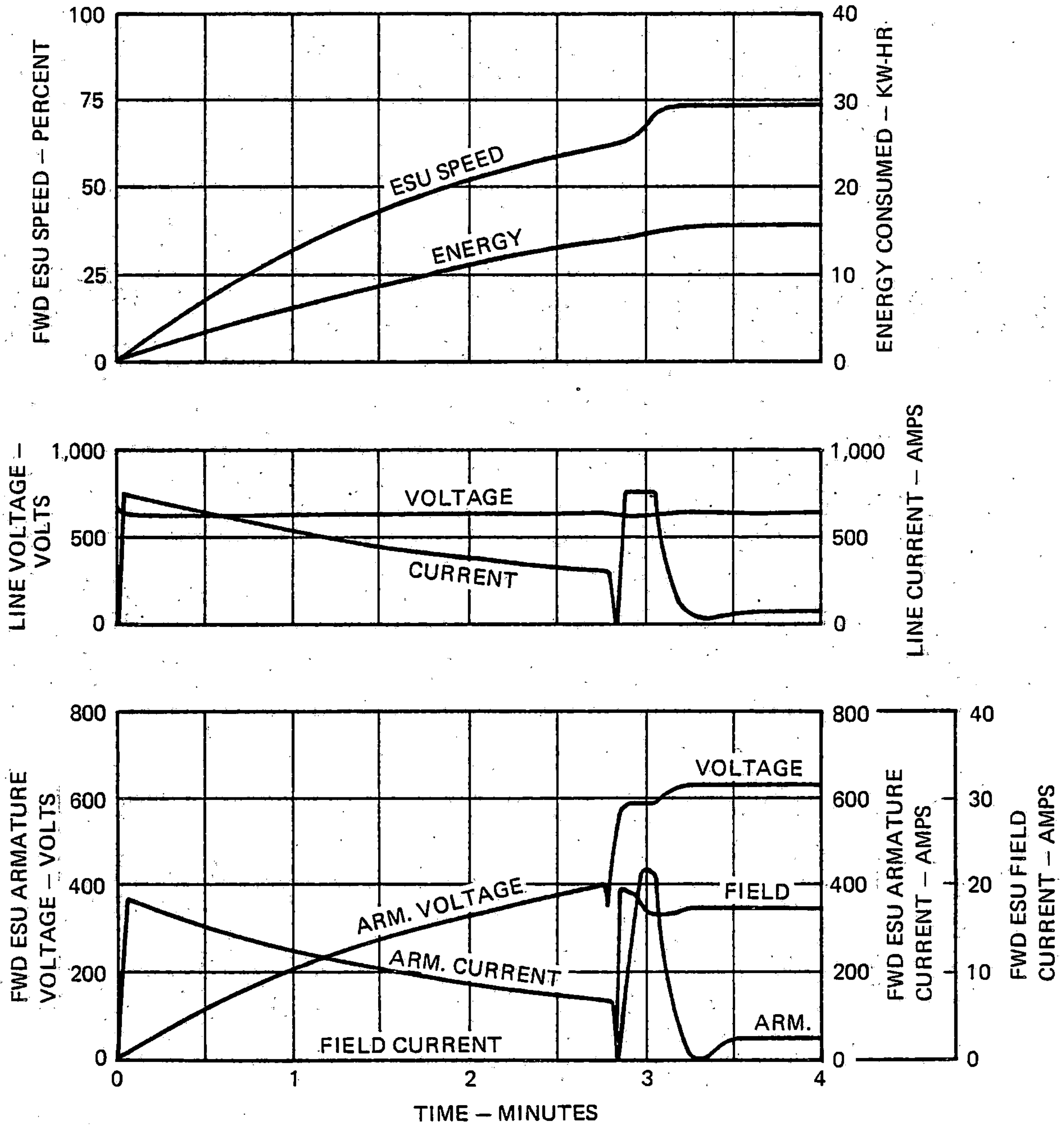


Figure 3–5. ESU Startup to Idle Speed Characteristics

NOTES: 1. STATIONARY CAR
2. ESU IDLE BOOST ON
3. ACT-1 PRELIMINARY TEST AND ADJUSTMENTS, DOT-TTC, PUEBLO, COLORADO

DOTX-4 RECORD: 567

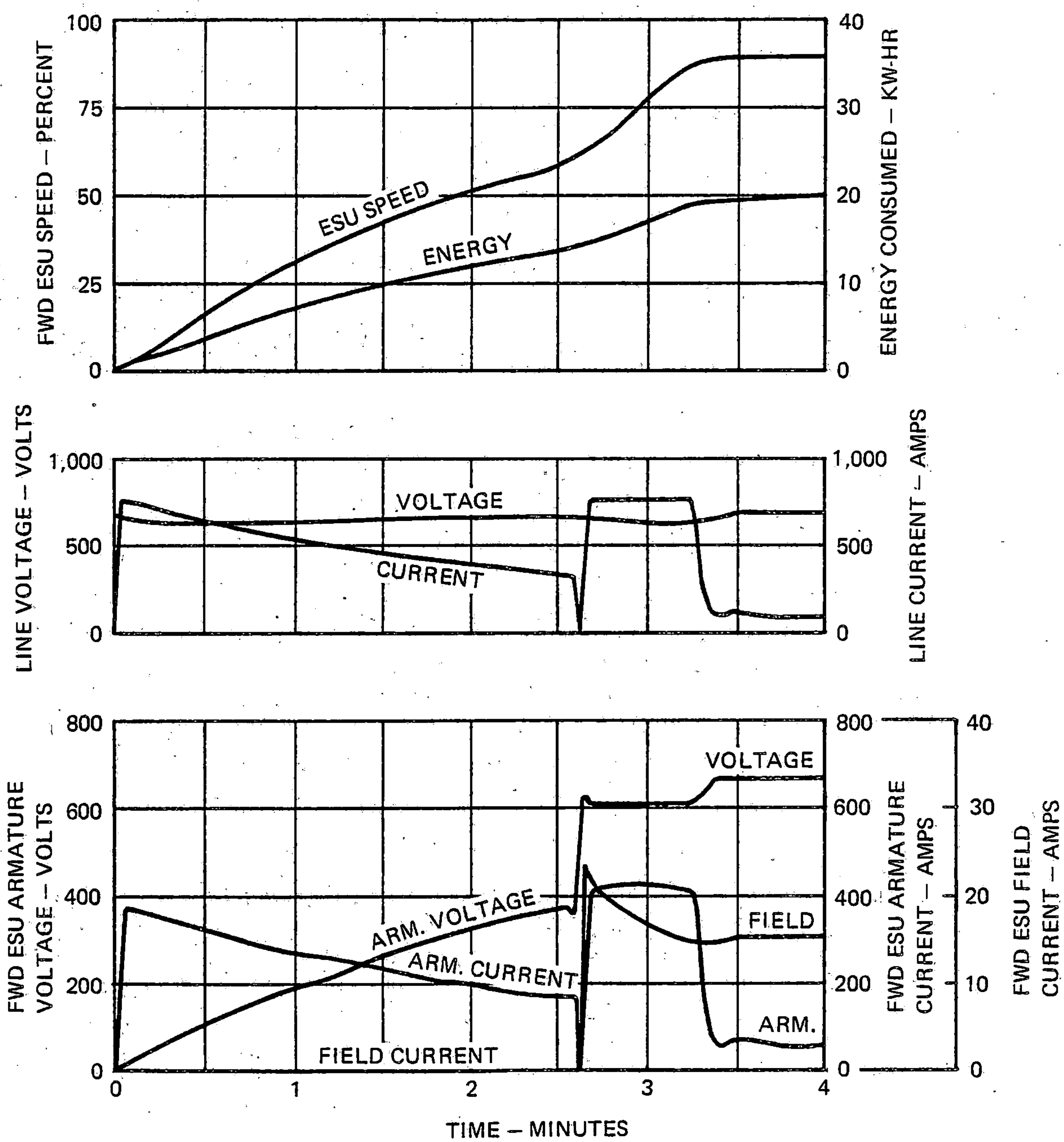


Figure 3–6. ESU Startup With Idle Boost On

NOTES: 1. STATIONARY CAR
2. ESU IDLE BOOST OFF
3. ACT-1 PRELIMINARY TEST AND ADJUSTMENTS, DOT-TTC, PUEBLO, COLORADO

DOTX-4 AND DOTX-5 RECORD: 895

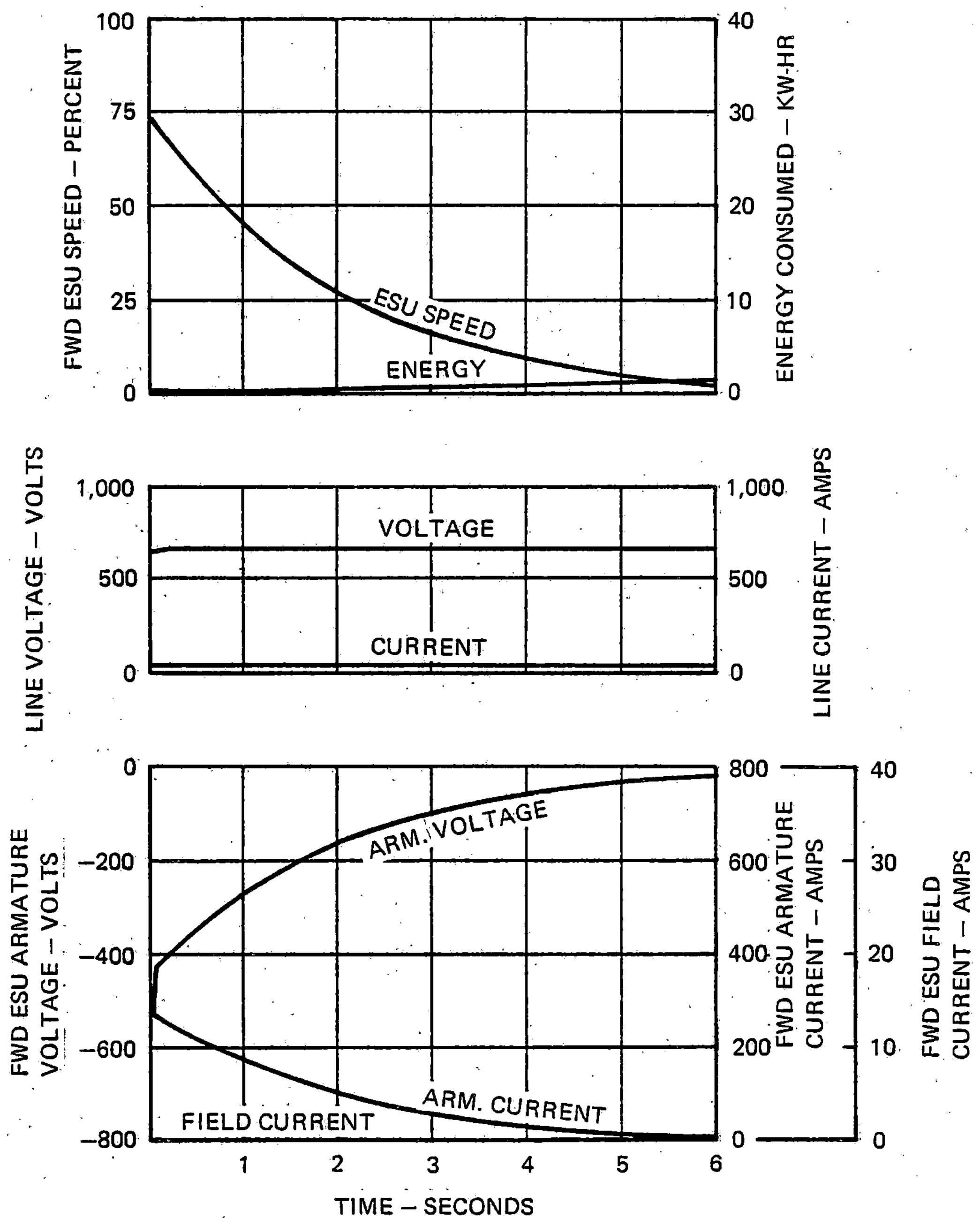


Figure 3–7. ESU Shutdown From Idle, Two-Car Train

3.3 ROLL CHECK TEST

Test Set No. ACT-P-0001-TT

Test Objective: Initial movement of vehicle under its own power to check propulsion, drive systems, and brakes. Test to be performed prior to each day's operation.

Test Description: Conduct initial tests using stinger power in the Transit Maintenance Building.

After initial tests and prior to each day's running on the transit test track, check drive, coast, and brake modes in forward and reverse directions, using third-rail power.

Status: The ACT-1 roll check test, PRCK-2-AW1-600S, was successfully completed in the TMB on DOTX-5 on November 9, 1977, and on DOTX-4 on January 18, 1978. Following this initial roll check test of each vehicle in the TMB, the roll check test, PRCK-2-SE1-600R, was performed at the start of each day's testing on the transit test track.

The normal test procedure on the transit test track was to perform the roll check before starting the conditioning run for each day's testing. The vehicle operator was instructed to move the vehicle in forward and reverse directions, using full service, deadman, and emergency brakes to stop the car. If any unusual noises, abrupt movements, or failures of the propulsion system or brakes were noted by the test crew, testing was suspended until the problem was solved.

3.4 HANDBRAKE TESTS

3.4.1 Handbrake Holding Test

Test Set No. ACT-B-0001-TT

Test Objective: To verify that the handbrake will hold an AW1 vehicle on a hill on the transit test track at Pueblo.

Test Description: Park the vehicle on a hill on the transit test track at Pueblo and apply the handbrake. Release all other brakes. Verify that the handbrake will hold the vehicle on grade.

Status: The ACT-1 handbrake holding test, PHNB-2-AW1-0, was successfully completed on DOTX-4 on May 31, 1978, and DOTX-5 on June 20, 1978.

The vehicles were stopped on a hill and the handbrake was engaged. The EP valves for each truck were cut out pneumatically, leaving the car on the hill held only by the handbrakes. The handbrakes were released and the car was allowed to roll part way down the hill, where the handbrakes were reapplied, stopping the vehicle.

3.4.2 Handbrake – AW3 Holding Test

Test Set No.: ACT-B-0004-TT

Test Objective: To demonstrate that the force required to move the vehicle with the handbrake applied is greater than the force required to hold an AW-3 weight car on a 5-percent grade.

Test Description: The test vehicle will be ballasted to an AW3 weight configuration and located on a clean, dry, tangent track. A tow cable will be fabricated, including a load cell, and connected between the test vehicle and the towing locomotive. The cable arrangement will be parallel to the ground with a load cell of not less than 10,000-pound capacity.

Status: The ACT-1 handbrake, AW3 holding test, PHNB-1-AW3-0, was successfully completed on DOTX-5 on July 20, 1978. The test was conducted in the TMB using DOT-011 as a tow vehicle. With the service brakes cut out and the handbrakes applied, a towing force of 9,200 pounds was recorded on a CEC oscillograph from the load cell, which did not move the vehicle. The measured force, 9,200 pounds, exceeds holding an AW3-weight car on a 5-percent grade (130,000 pounds x 0.05 = 6,500 pounds) by 2,700 pounds and indicates that the handbrake is capable of holding an AW3-weight car on a 7-percent grade.

3.4.3 Handbrake/Propulsion Interlock Test

Test Set No. ACT-B-0002-TT

Test Objective: To verify that the handbrake (park brake on the ACT-1 vehicles) interlock will prevent the propulsion system from moving the car with the park brake applied.

Test Description: With the park brake applied, the propulsion system controls shall be engaged in an attempt to move the vehicle. The park brake/propulsion interlock shall prevent the vehicle from moving.

Status: The ACT-1 park brake/propulsion interlock test, PHBI-2-AW1-600R, was successfully completed on DOTX-4 on May 31, 1978, and on DOTX-5 on June 20, 1978.

The vehicles were powered up on the transit test track at Pueblo, using normal startup procedures. The vehicle operator was instructed to attempt to drive the vehicles with the park brake applied. The vehicles did not respond to a maximum drive command in either the forward or reverse direction.

3.5 ANTIROLLBACK TEST

Test Set No. ACT-P-0002-TT

Test Objective: To verify that the vehicle will not roll back when started with minimum tractive effort on an incline.

Test Description: With the vehicle parked on an incline and the antirollback system engaged, apply minimum tractive effort to accelerate the vehicle uphill.

Status: The ACT-1 antirollback test, PARB-2-AW1-600R, was successfully completed on DOTX-4 on May 31, 1978, and on DOTX-5 on June 23, 1978.

The vehicles were stopped on a hill on the transit test track at Pueblo and then driven uphill with a forward drive command. With the antirollback defeat on, the car was observed to roll back before moving forward as commanded. With the antirollback system engaged (control switch off), the vehicle did not roll back before moving forward.

3.6 SPEED CALIBRATION

A cab speedometer calibration test was performed for each car by manually recording the speed indicated by the cab speedometer and ninth wheel while the car was maintained at a steady speed. This was done at 10- or 20-mph increments up to a speed of 80 mph. The results for DOTX-4 and DOTX-5 are shown in Figures 3-8 and 3-9, respectively. This test provides a check of the cab speedometer relative to the instrumentation system ninth-wheel speed. The time to traverse a measured distance was not recorded to determine the error relative to a true speed measurement.

It can be seen in Figures 3-10 and 3-11 that the cab speedometer is in close agreement with the ninth-wheel speed. With the exception of DOTX-4 at 40 mph and below, the cab speedometer reads slightly higher (0.9 percent) than the ninth-wheel speed. For DOTX-4 below 40 mph, the cab speedometer reads up to 2 percent lower than the ninth-wheel speed. In all cases, the cab speedometer and ninth-wheel speed read within 0.7 mph of each other.

3.7. HEATING, VENTILATING, AND AIR CONDITIONING (HVAC)

3.7.1 Summary

The heating, ventilating, and air-conditioning system (HVAC) performance tests were conducted at the Transportation Test Center in Pueblo, Colorado, to verify the proper system operation and to substantiate performance of the system as installed in the vehicle.

The test data verified that the capacity of the duct and floor heaters is marginally adequate to meet the cold-day heating requirements at sea level conditions, providing the quantity of the fresh air intake does not exceed the specification minimum fresh air requirement. However, the floor heater grill temperatures of up to 324°F exceed the specification maximum of 125°F for revenue service. New floor heater elements which distribute the heat over a greater area would be required to meet grill temperature criteria.

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 600 VOLTS, NOMINAL LINE VOLTAGE
4. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 RECORD: 587

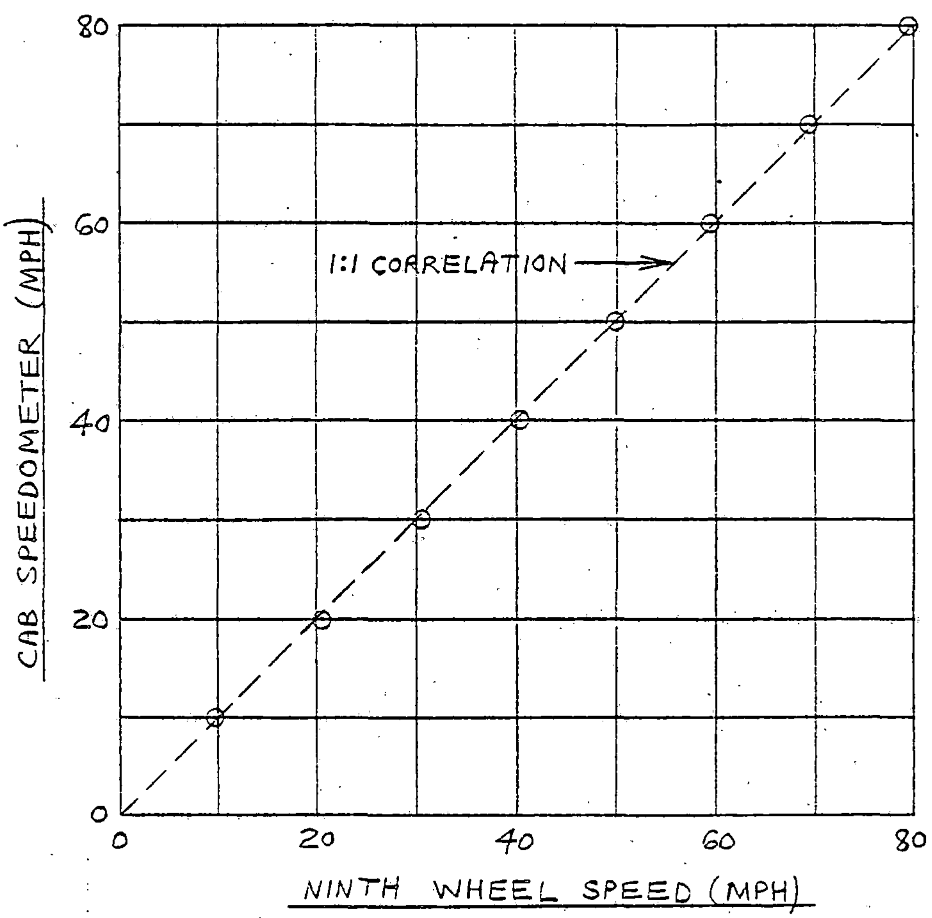


Figure 3–8. Speed Calibration, DOTX-4

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 600 VOLTS, NOMINAL LINE VOLTAGE
4. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-5 RECORD: 817

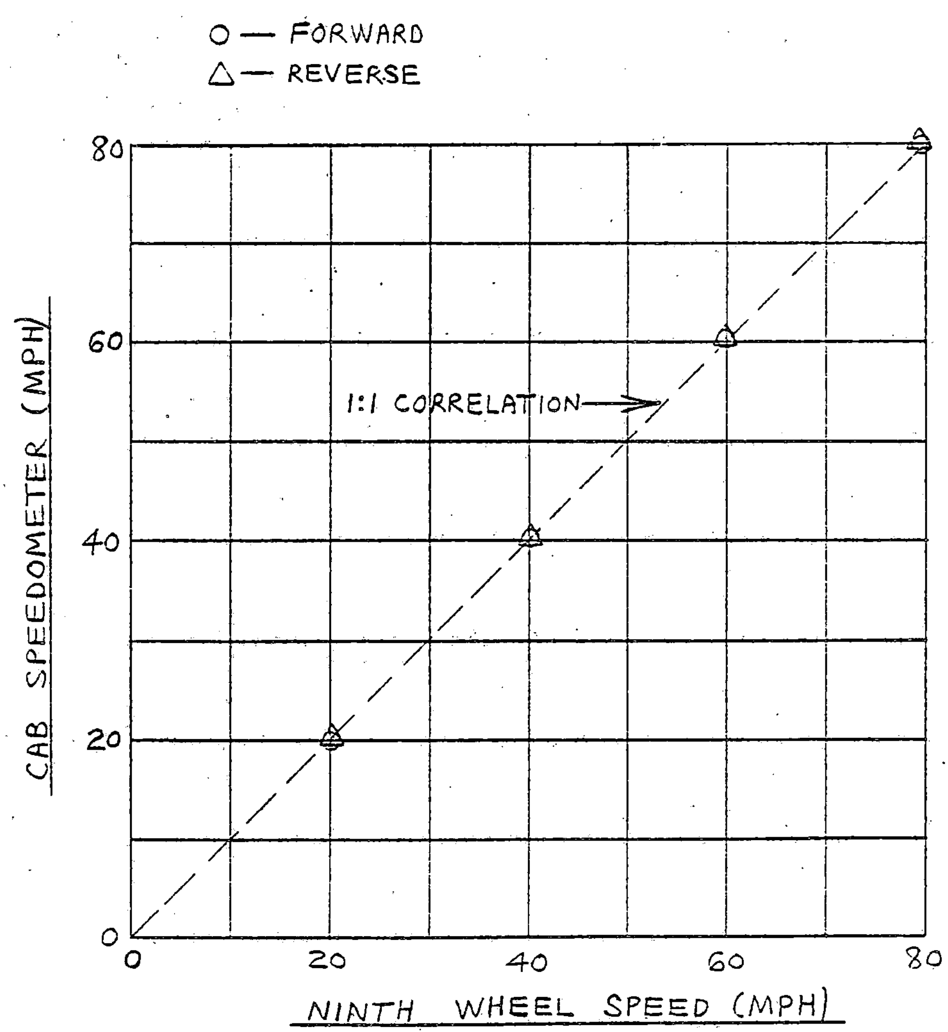


Figure 3–9. Speed Calibration, DOTX-5

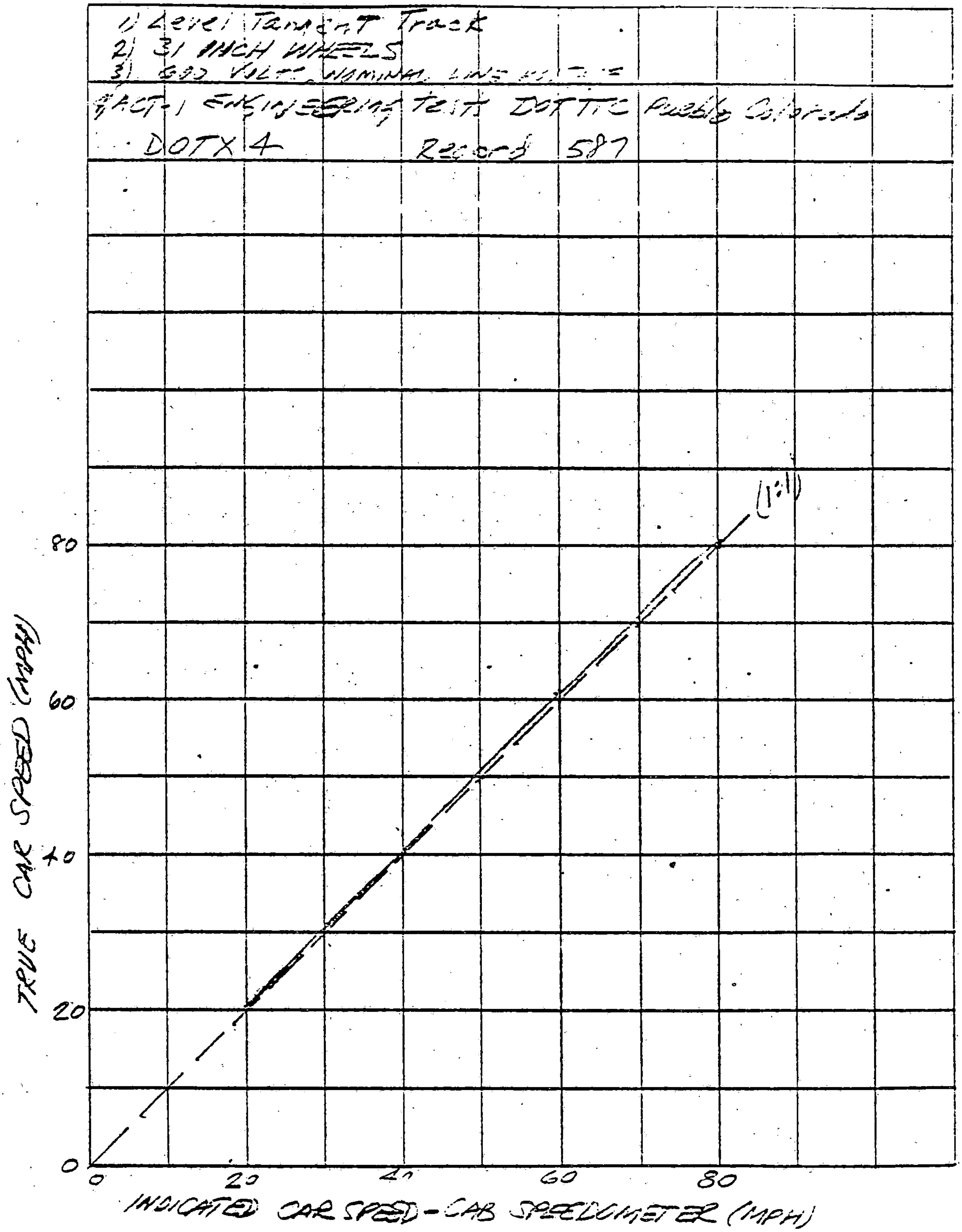


Figure 3–10. Speed Calibration, Cab Speedometer, DOTX-4

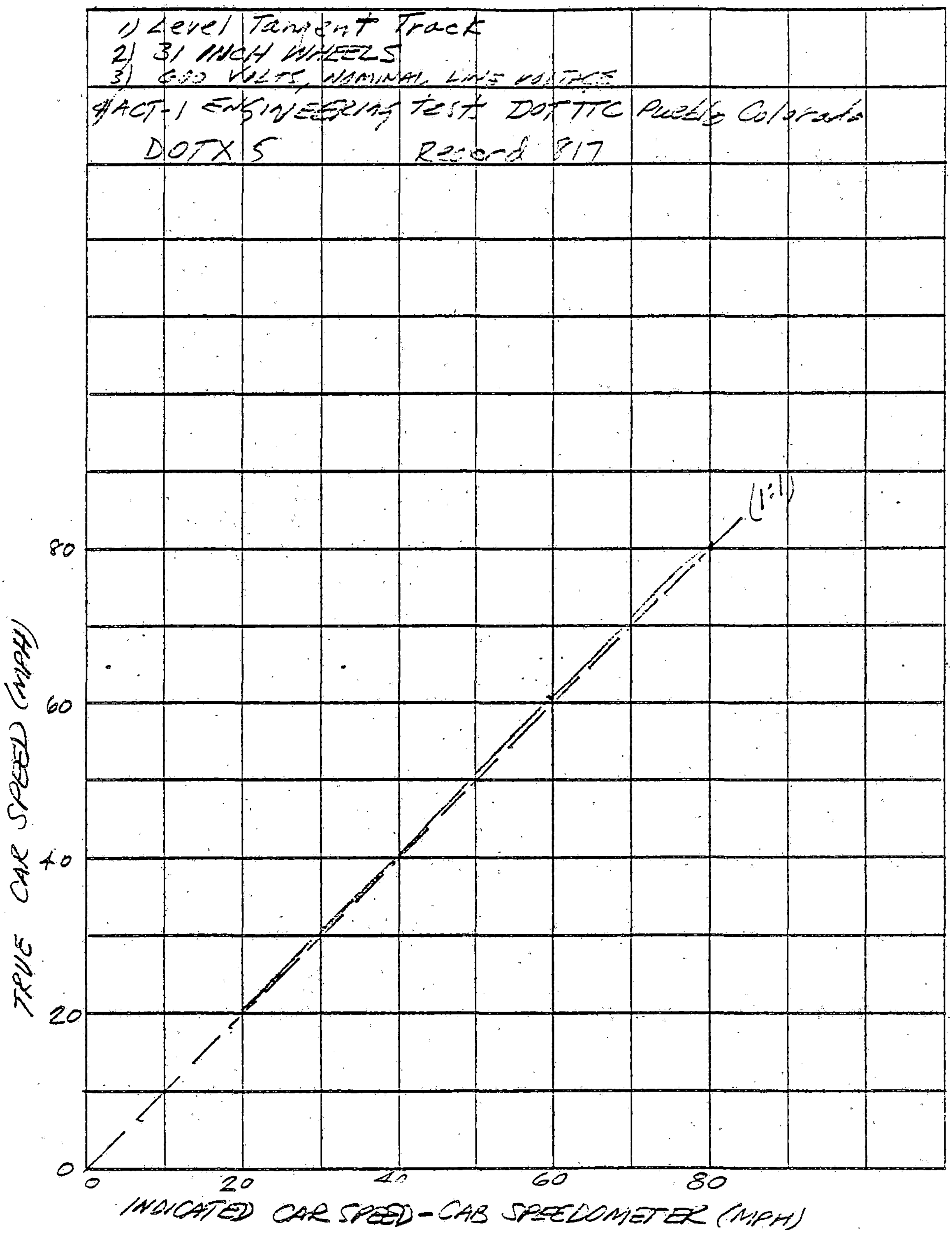


Figure 3–11. Speed Calibration, Cab Speedometer, DOTX-5

The air-cycle air-conditioning system as installed in the ACT-1 vehicle was recognized as being inadequate based on vehicle functional test results obtained at Garrett and documented in report UMTA-IT-06-0026-79-2. However, the subsystem tests performed at Garrett showed that the air-cycle system cooling capacity met the refrigeration requirement. These tests verify that excessive carbody losses caused the air-conditioning system deficiencies as installed in the vehicle.

A comparison of equivalent air-cycle and vapor-cycle systems shows that the air cycle consumes approximately twice the power of a comparable vapor-cycle unit (40 hp versus 20 hp, respectively), but the air-cycle system weighs less than half the vapor-cycle unit (850 lb versus 2,000 lb, respectively). The air-cycle system is easier to maintain than a pressurized vapor-cycle system. The big advantage of the air-cycle system in the ACT-1 was its tolerance of the variable-speed, variable-frequency power derived from the energy storage unit. An equivalent vapor-cycle unit would require a constant-speed drive.

The air-cycle air-conditioning system is worthy of consideration for future transit car applications.

3.7.2 Test Objectives

The objectives of the HVAC system test at Pueblo were to demonstrate that the system was functioning properly and to substantiate performance within the vehicle. The objectives are summarized below:

a. To verify operation in all modes of operation.

b. To verify that temperature set points are within specification.

c. To verify surge-free and ice-free operation of turbocompressors.

d. To verify layover performance operation.

e. To determine vehicle heat transfer coefficient (UA).

f. To conduct warmup and heating capacity test.

g. To conduct door-cycling heat recovery test.

h. To conduct air-conditioning capacity and humidity control checkout.

3.7.3 Test Description

The tests were of two basic types: 1) functional/operational, and 2) performance.

3.7.3.1 Functional/Operational Tests

Each HVAC subsystem was tested with the ESU's operating to assure the proper operation of the subsystem and to make final control operation adjustments as required. Each subsystem (port and starboard pack) was checked individually for proper vent fan, turbocompressor, and heating operation. The comfort control unit (CCU) shown in Figure 2-41, in conjunction with the temperature control panel shown in Figure 2-40, were exercised through the various modes to verify temperature set points.

3.7.3.2 Performance Tests

Cold-day performance tests were conducted with the car parked on the north spur outside the Transit Maintenance Building (TMB). The tests were conducted during the nighttime hours in order to obtain a stabilized outside ambient temperature. Sunrise caused a very rapid change in temperature, so all testing was terminated each day before sunrise.

A static test transfer coefficient (UA) test was conducted on both cars. The dynamic heat transfer coefficient was determined for DOTX-5 only. The heater layover performance, warmup, heat capacity, and door-cycling recovery time tests were conducted with DOTX-5.

Hot-day performance testing was constrained by insufficient cooling capacity of the air-conditioning system to cope with the significantly greater carbody and ducting heat transfer than was predicted.

3.7.4 Test Instrumentation

The instrumentation installed in the ACT-1 car for the HVAC system performance evaluations is as follows:

1. A thermocouple temperature grid as shown in Figure 3-12 was located at each doorway location as shown in Figure 3-13.

2. Twelve thermocouples at duct outlets, outside ambient, and roving as shown in Figure 3-14.

3. The HVAC pack temperature and pressure sensor locations are shown in Figure 3-15.

4. Eighteen electric resistive-type heaters (750 watts at 208 volts) located as shown in Figure 3-13.

5. Four recirculation fans (115 volts, 60 Hz, 0.85 amp) located as shown in Figure 3-13.

6. Voltage and current draw in floor and duct heater circuit breakers.

3.7.5 Test Procedure

The HVAC tests conducted at the Transportation Test Center generally followed the vehicle heating, ventilating, and air-conditioning system test procedure at TTC, document 77-14307, Revision A, dated 14 November 1977. Deviations from this plan are described below for the appropriate paragraph from the test plan.

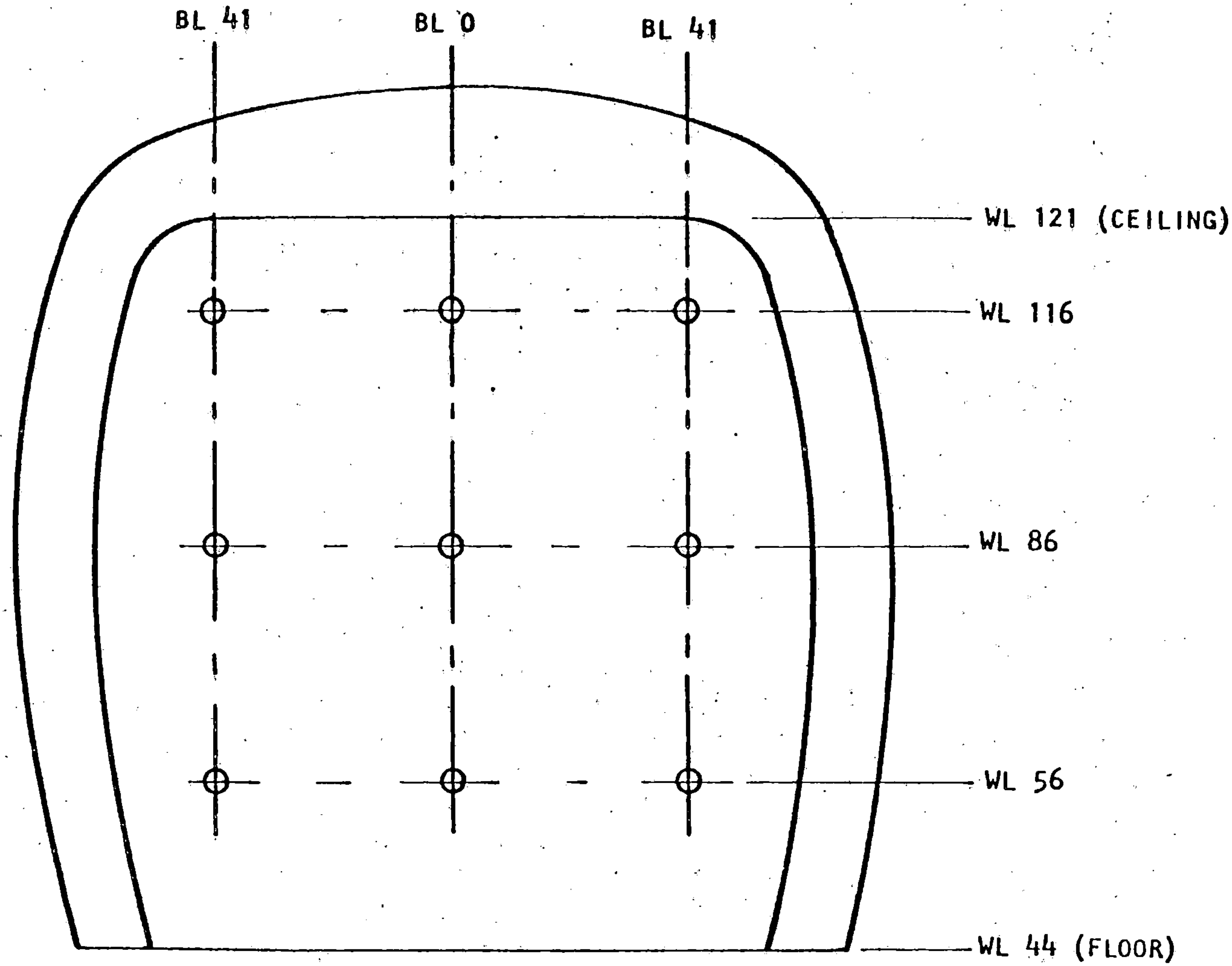


Figure 3–12. Thermocouple Grid

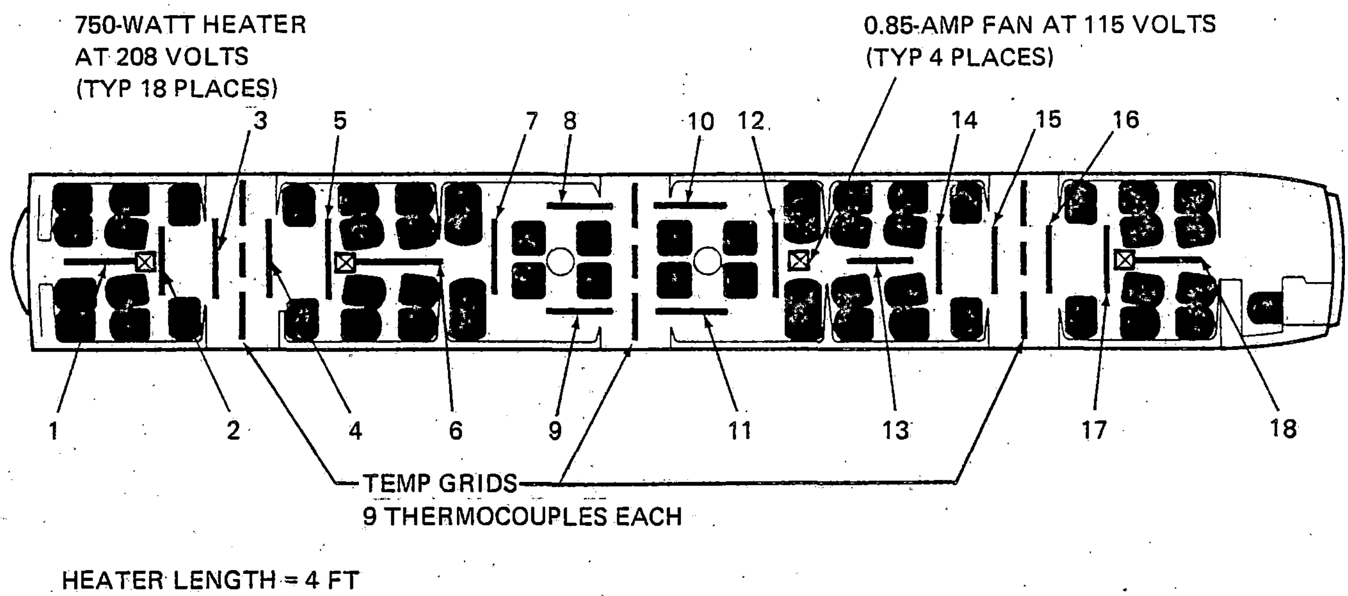


Figure 3–13. Thermocouple Grid and Heater Layout

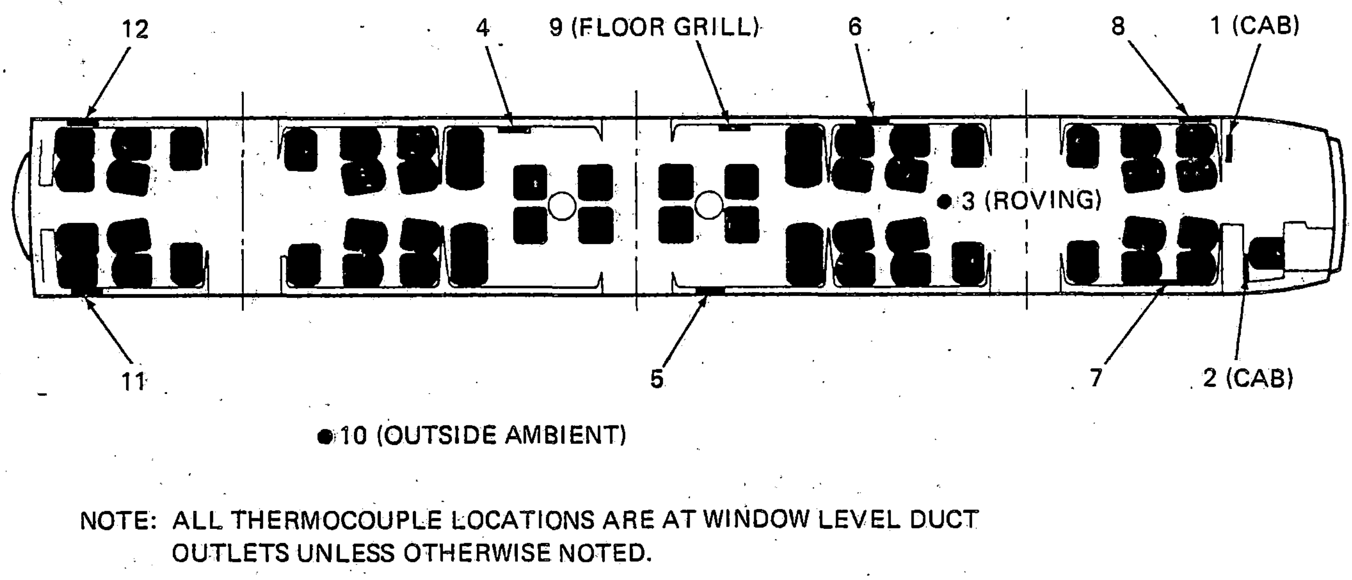


Figure 3–14. Air Duct Thermocouple Locations

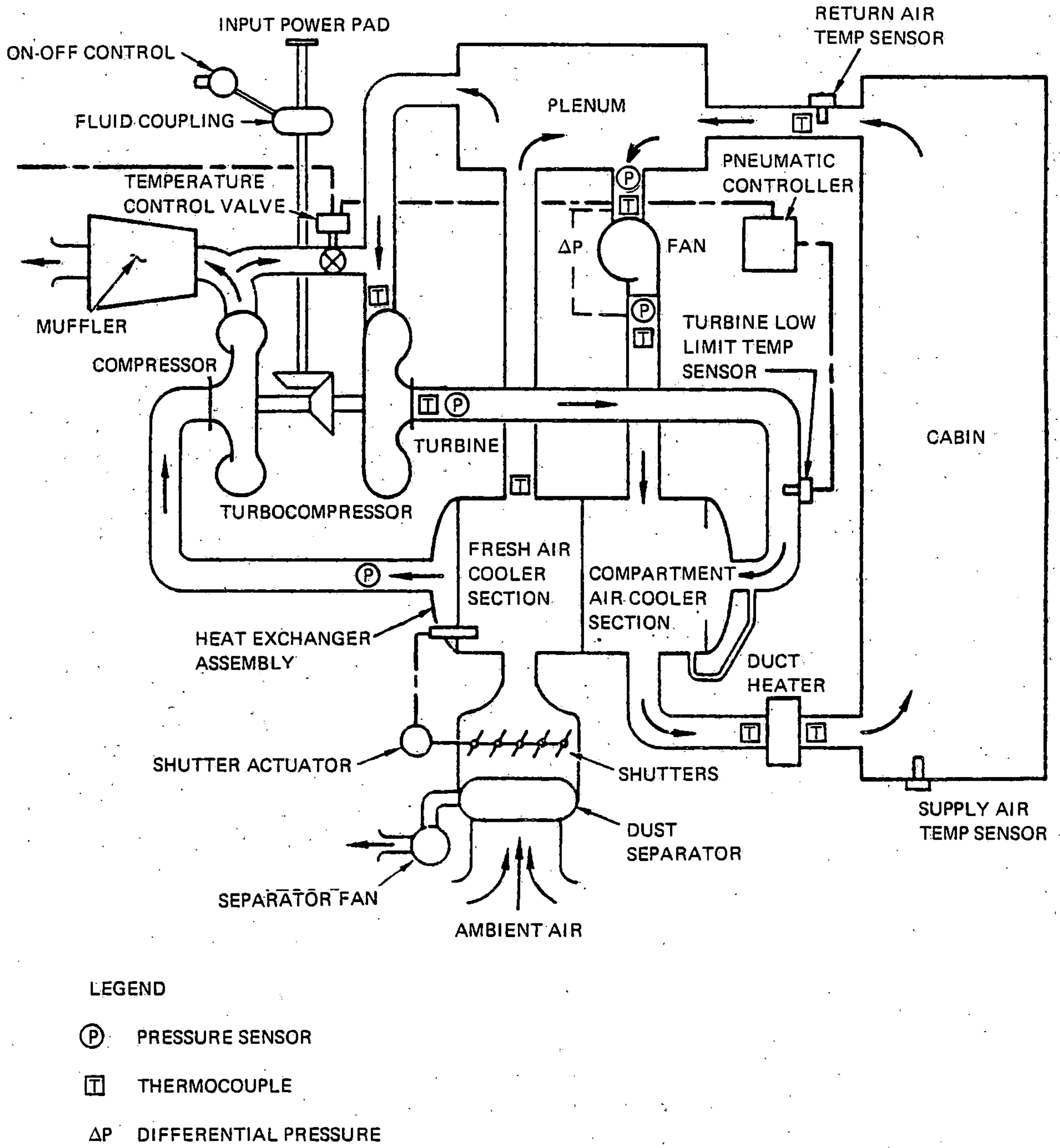


Figure 3–15. HVAC Pack Instrumentation

Para 1.6.5(2) – No special attempt was made to seal the doors.

Para 1.6.6 – The ESU's were operated at 85-percent speed and the ventilation fans were on.

Para 1.7 – The ambient temperature was 41°F, which was the lowest temperature the night of this test.

Para 1.8.2 – The door-recovery cycle test was terminated after 30 minutes due to sunrise. Sufficient data was obtained.

3.7.6 Test Results

3.7.6.1 Functional Tests

The functional tests verified that the HVAC systems are operational in all modes. However, the temperature set points at which the heaters and/or turbocompressors are activated and deactivated were out of specification and were reported by Trouble Report 054. The set point is the temperature at which the temperature selector on the temperature control panel is set. The deviation of events compared to the desired error signal is shown in Figures 3-16 and 3-17 for the port and starboard packs, respectively.

Trouble Report 054 was resolved by sending an AiResearch HVAC specialist to Pueblo to reset the controls to the design criteria.

3.7.6.2 Layover Performance Test

The heater layover performance test was conducted on DOTX-5 per paragraphs 1.6 through 1.6.4 of the test procedure. The layover thermostat was set at 55°F. Exterior temperature was 36.5°F and the interior temperature was 41.5°F at the start of the test.

The test was initiated by activating floor heaters and monitoring the interior temperature by averaging the thermocouple grid temperatures. After approximately one hour of floor heater operation, the average interior temperature exceeded 76°F and still had not stabilized. The panel was removed to adjust the thermostat to 45°F. A review of the thermostat location indicated that the thermostat was sensing exterior wall temperature rather than carbody interior temperature; further testing was futile and therefore testing was terminated.

It was concluded that the layover heater operation mode would not be used at Pueblo and therefore no further effort was expended on layover operation. If the ACT-1 should be rescheduled for property demonstration, it is believed that relocation or rework of the thermostat installation is a minor problem and that the layover heater will function properly when the thermostat senses interior temperature.

It was significant to note that floor heater grill temperatures up to 324°F were recorded during the layover heat test. This is far in excess of the 125°F maximum specification requirement.

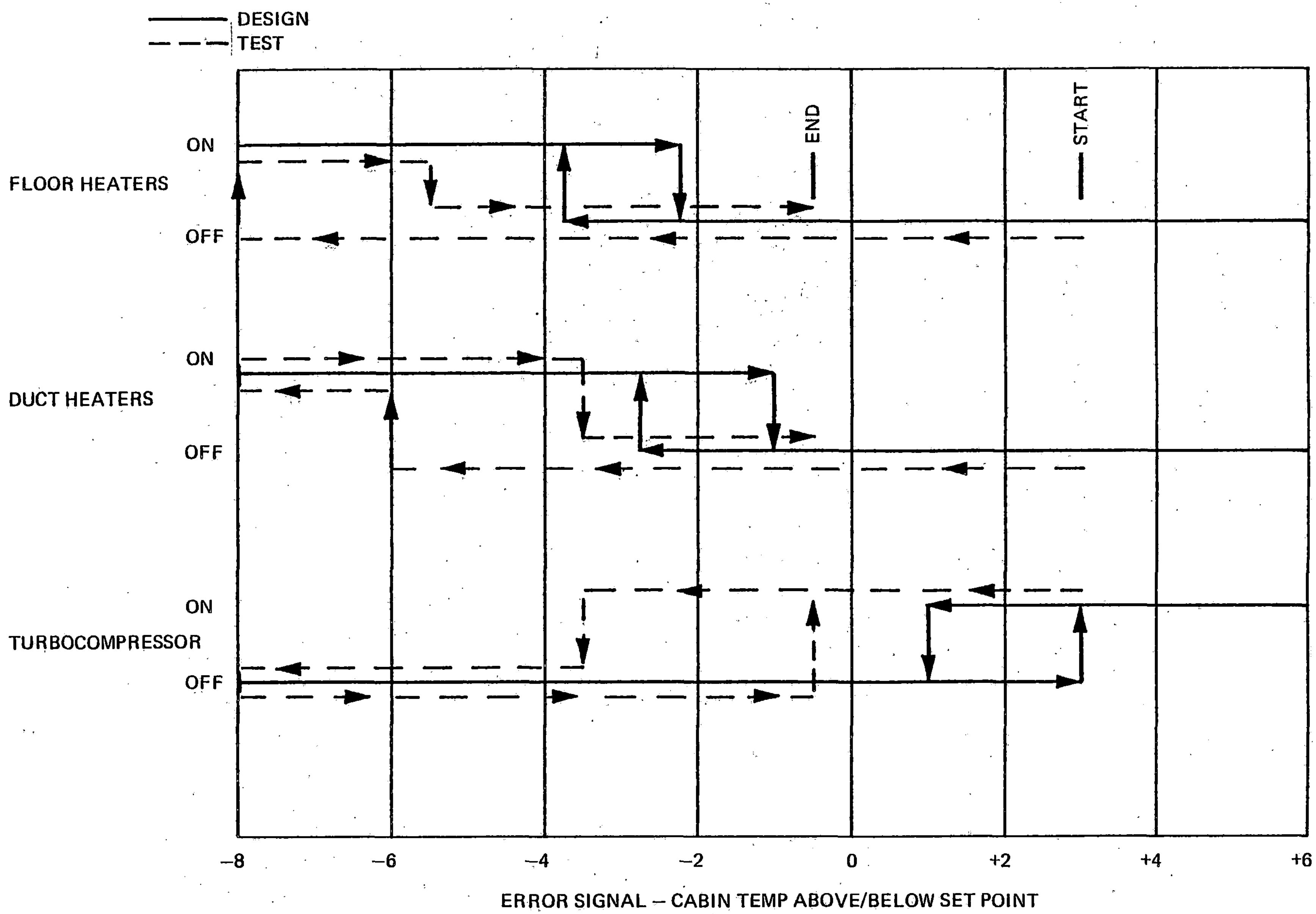


Figure 3–16. HVAC Operation, Port Side

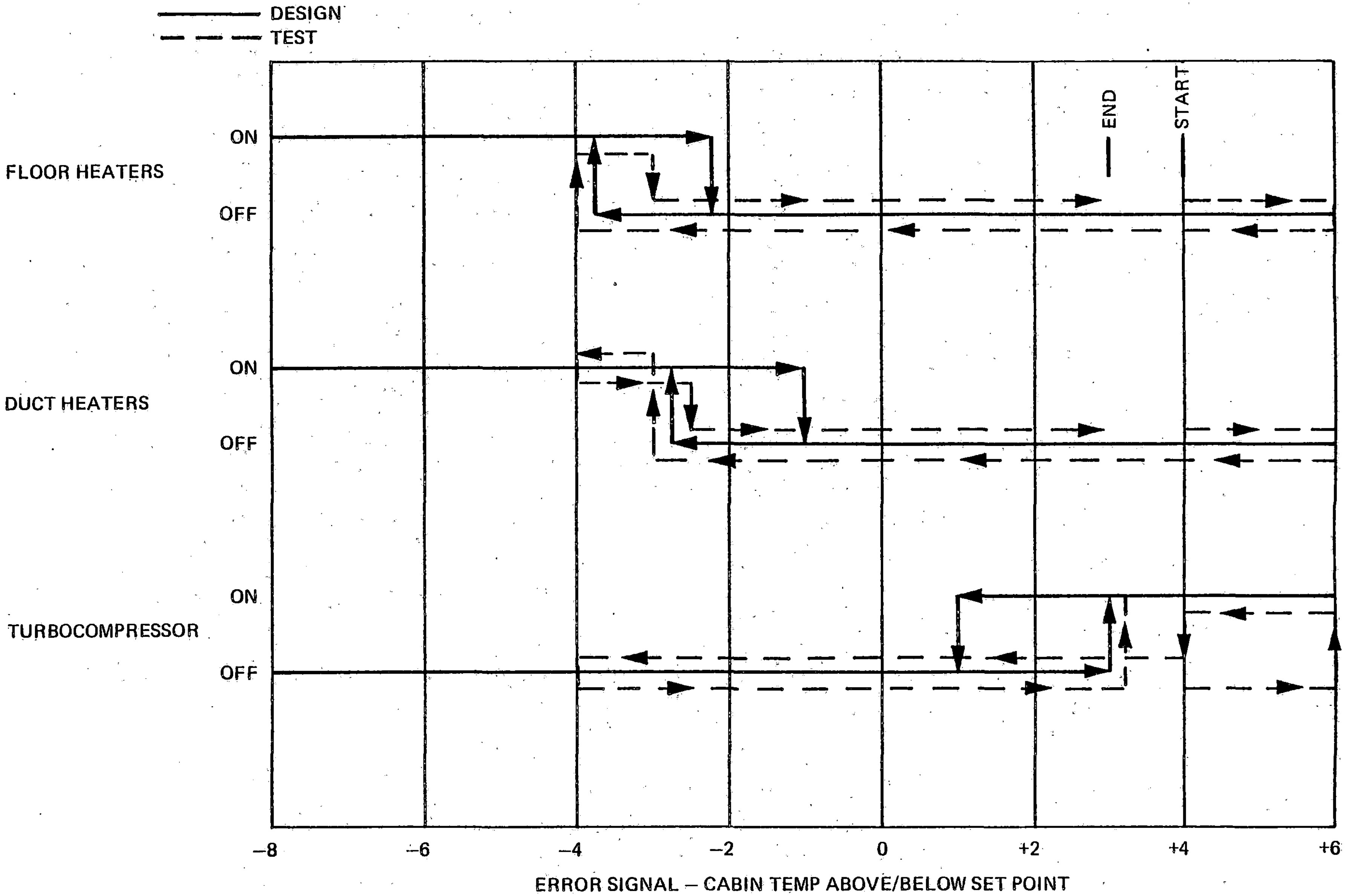


Figure 3–17. HVAC Operation, Starboard Side

3.7.6.3 Heat Transfer Coefficient (UA)

The heat transfer coefficient for the ACT-1 carbody was determined for both a static car (all systems dead) and an operating car (85-percent ESU speed). The static condition was tested on both DOTX-4 and DOTX-5, but the dynamic test with the car operating was conducted on DOTX-5 only. All testing was conducted between midnight and sunrise to eliminate solar heating and the fresh air intake vents were blocked. The test results are summarized in Table 3-IV. The static heat transfer coefficient is in close agreement with the design goal; however, the dynamic coefficient is nearly double the design value. Under the static test condition, the interior liners provide additional insulation between the heat source (heaters set on the floor) and the outside walls, while in the true operational condition, the heated air from the duct heater passes between the interior liners and exterior walls and roof and also passes through the duct system. Results of these tests indicate that the carbody/duct insulation is inadequate and/or air infiltration is excessive.

3.7.6.4 Warmup and Heating Capacity

The warmup and heating-capacity test was conducted on DOTX-5 with the ESU's operating at 85-percent speed and the fresh air intake vents open. The exterior temperature was 41°F, which was above the desired 40°F, but a lower temperature was not expected that night and therefore the test was started.

TABLE 3–IV. HEAT TRANSFER COEFFICIENT (UA) DATA

Parameter	Vehicle/Condition DOTX-4/Static	DOTX-5/Static	DOTX-5/Dynamic
Power Inputs (kw)			
Lights and instr	0.545	0.654	0.329
Vent fans			6.80
People	0.234	0.117	0.176
Heaters	13.033	13.249	13.099
Total power	13.812	14.029	20.404
Stabilized Temp (°F)			
Interior	84.7	92.4	73.9
Exterior	21.5	31.9	25.5
Δ Temp	63.2	60.5	48.4
UA – Btu/hr °F	746	791	1,439

NOTES: 1. Above data includes normal air infiltration.
2. Equivalent design UA = 736 Btu/hr °F.

The interior temperature time history is shown in Figure 3-18. The time to 68°F was 18 minutes. The interior temperature stabilized about the 75°F controller set point but initial problems were encountered with heater operation. Initially the port duct and floor heaters were cycling while the starboard heaters remained off. Adjustments were made until the port and starboard duct heaters were cycling and the floor heater remained off.

A summary of the test data is shown in Table 3-V. It is significant to note that the starboard duct heater was on significantly longer than the port duct heater due to the fact that the fresh air drawn in the port side was 14°F warmer than the starboard side due to the 5-mph wind blowing the undercar heat to the port side.

The calculated heat transfer coefficient of 1,219 Btu/hr °F is 18 percent lower than calculated for the dynamic condition reported in paragraph 3.7.6.3. This difference is not considered significant because the fresh air intake measurements were not precise and air infiltration can

TABLE 3—V. DOTX-5 HEATING PERFORMANCE TEST DATA

Test Interval Conditions	
Stabilized outside air temp	41°F
Stabilized interior temp	74.8°F
Port fresh air inlet temp	55°F
Port fresh air supply	830 cfm
Stbd fresh air inlet temp	41
Stbd fresh air supply	830
Port duct heater on 42.3% of time	
Stbd duct heater on 62.2% of time	
Port and stbd floor heaters off	
Heater supply voltage	660 volts
Power Summary	
Vent fans	6.8 kw
Car lights	1.875 kw
Instrumentation	0.400 kw
Three people	0.176 kw
Port duct heater	6.091 kw
Stbd duct heater	8.957 kw
Total	24.299 kw
Air density = 0.06486 lb/ft^3	
Calculated UA = 1,219 Btu/hr °F	

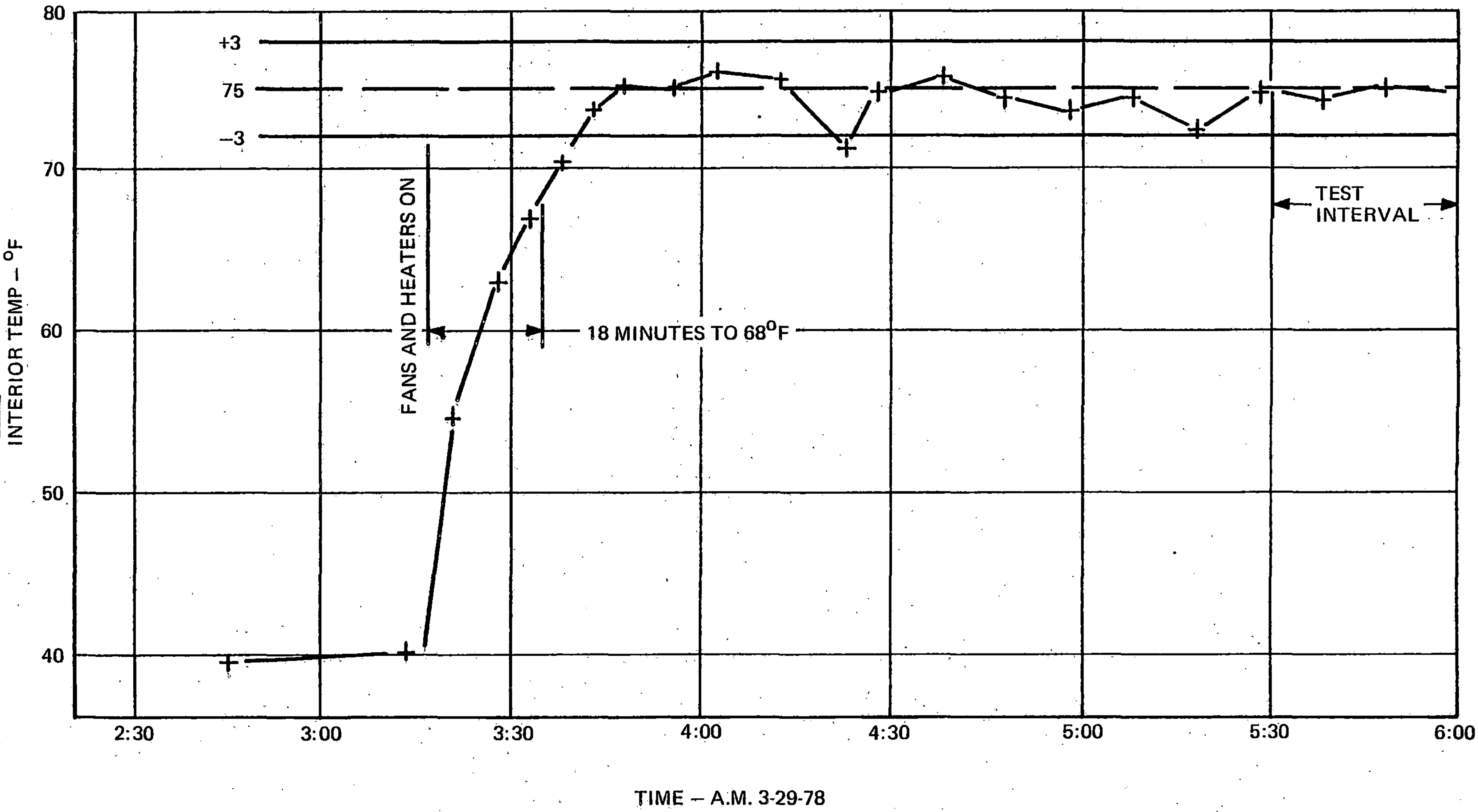


Figure 3–18. DOTX-5 Heat Performance Test

vary with and without fresh air intake. The test results are compared with the cold-day design requirements in Table 3-VI. The data shows that the actual heating requirements are approximately 50 percent greater than the design requirements. However, a total of 35 kw of heating is actually available, 20 kw from the duct heaters and 15 kw from the floor heaters.

3.7.6.5 Door-Cycling Heat Recovery

The door-cycling heat recovery test was initiated after the interior temperature had stabilized at approximately 75°F. The test results shown in Figure 3-19 indicate a typical door-cycling temperature recovery of 55 percent within 30 seconds after closing the doors. This compares with a 67-percent recovery test requirement.

3.7.6.6 Air-Conditioning Performance

The air-cycle air-conditioning system as installed in the ACT-1 car was unable to provide adequate cooling capacity. A review of the HVAC half-car system test revealed that the cooling capacity of the HVAC system is 16 tons at 85-percent flywheel speed, which should have been quite adequate for Pueblo test conditions with low passenger loads. However, adjustments of the air-conditioning system by Garrett specialists failed to provide a comfortable cabin temperature.

TABLE 3–VI. HVAC DESIGN COLD-DAY TEST DATA

Source	Design	Test
Car sensible load		
Walls and roof	–11,110	
Floors	– 7,780	
Windows (conduction only)	–21,900	–106,053
Infiltration	–23,200	
Electrical	+17,100	+ 17,100
Passengers	0	0
Total	–46,880 (13.7 kw)	– 88,953 (26.1 kw)
Fresh air heating (80-percent recirculation)	–59,650	– 59,650
Latent load	0	0
Ventilation fans	+20,150	+ 21,150
Total electrical heater power requirements	86,380 (25.3 kw)	128,453 (37.6 kw)
Design conditions:		
–15°F ambient temperature		
No solar or passenger load		
72°F compartment temperature		

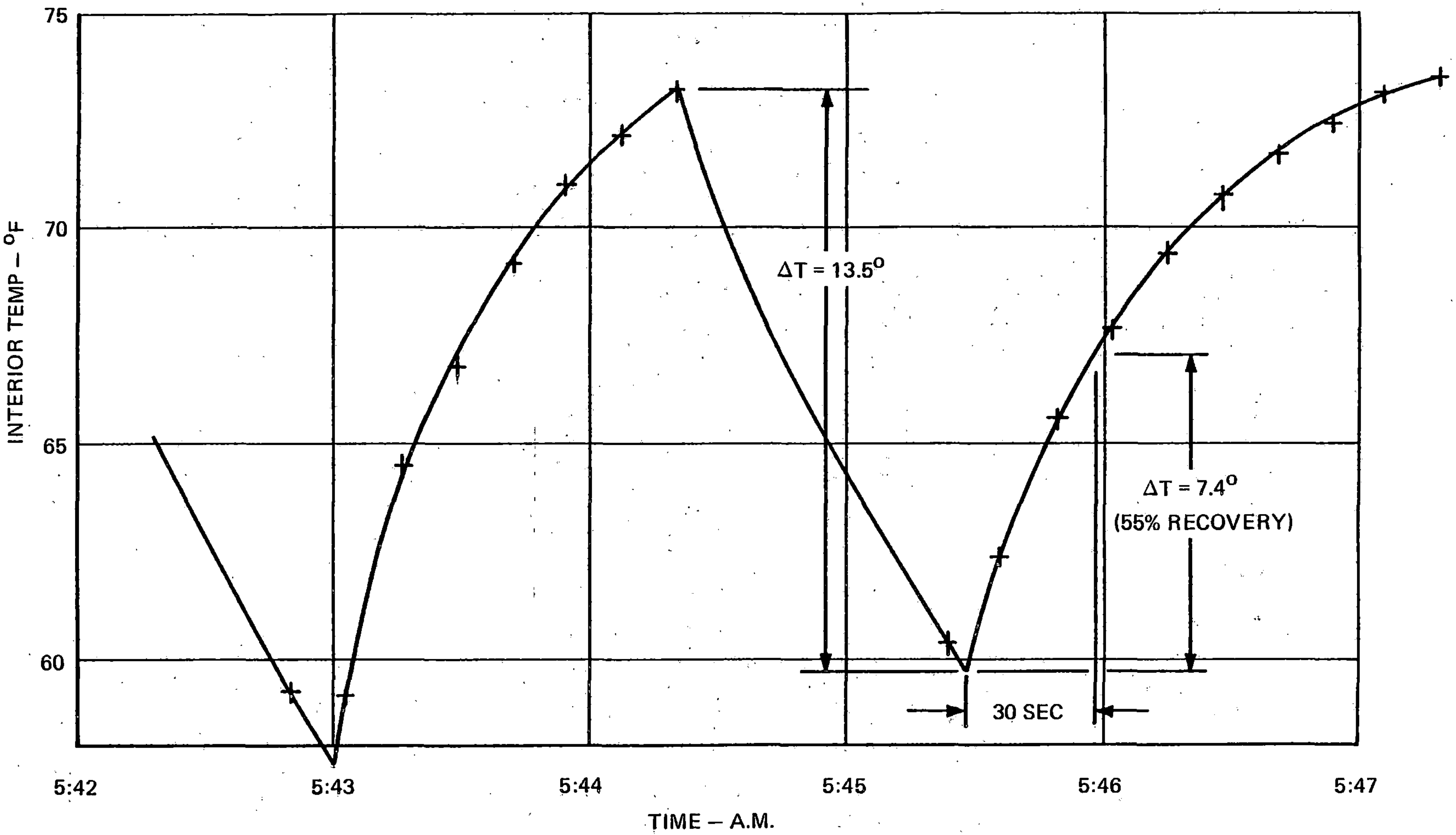


Figure 3–19. Door Cycling Heat Recovery

A supplemental water spray system was installed on a test basis to improve the heat exhanger efficiency. No technical data was measured, but the subjective opinion of the test crew was that cabin comfort was improved considerably. Attempts at reclaiming water from the spray system and returning it to the water storage tank were unsuccessful and therefore it had to be dumped overboard, which resulted in depleting the water supply in about 2 hours. As a result, the supplemental spray system was removed because the crew felt it better to have a uniform (although uncomfortable) cabin temperature throughout the test shift.

The inadequate air-conditioning problem was not solved during the TTC test program. It is believed that the deficiency is primarily in the carbody and/or ducting and not in the basic capacity of the HVAC packs. Therefore, air-cycle air-conditioning is still considered a viable alternative to the vapor cycle for transit car applications.

3.8 COLLISION ATTENUATION

3.8.1 System Description

The ACT-1 vehicle is equipped with a collision attenuation system on each end to allow the railcar to sustain low-speed end impacts without permanent structural damage. In such impacts, the vehicle energy is absorbed by hydraulic cylinders which are actuated by a sliding-coupler carrier assembly structure attached to the anti-climber. Except for replaceable shear pins, the system is fully reusable and requires no external energy source. The major elements of the collision attenuation system are shown in Figure 2-7.

The collision attenuation system at each end includes two hydraulic cylinders which absorb the impact energy when the system is activated. The anticlimber/coupler carrier assembly is restrained from activating the system during routine coupling or draft loads by two shear pins. When an impact force exceeds approximately 180,000 pounds, the shear pins fail and the hydraulic cylinders are activated. The A-end cylinders have a stroke of approximately 14.5 inches and the B-end cylinders have a 5.5-inch stroke. The A-end cylinder incorporates a metering pin which reduces impact forces at low speeds but develops the full 90,000-pound force per cylinder at higher speeds, as shown in Figure 3-20. The B-end cylinders do not incorporate a metering pin and therefore develop the full 90,000-pound force immediately.

The theory behind a different cylinder at the A and B ends is that in revenue service the B end is always mated with another B end and the two collision attenuation systems acting in series are approximately equivalent to the A end impacting a brick wall.

3.8.2 Impact Tests

The hydraulic cylinder design characteristics of the A-end collision attenuation system were used to generate predicted response data for various configurations (with and without shear pins, coupler, etc) at various impact speeds into a rigid barrier. A collision attenuation system test program was conducted on the north TMB spur to obtain data for evaluation with the predicted characteristics. Car DOTX-5 was used for these tests.

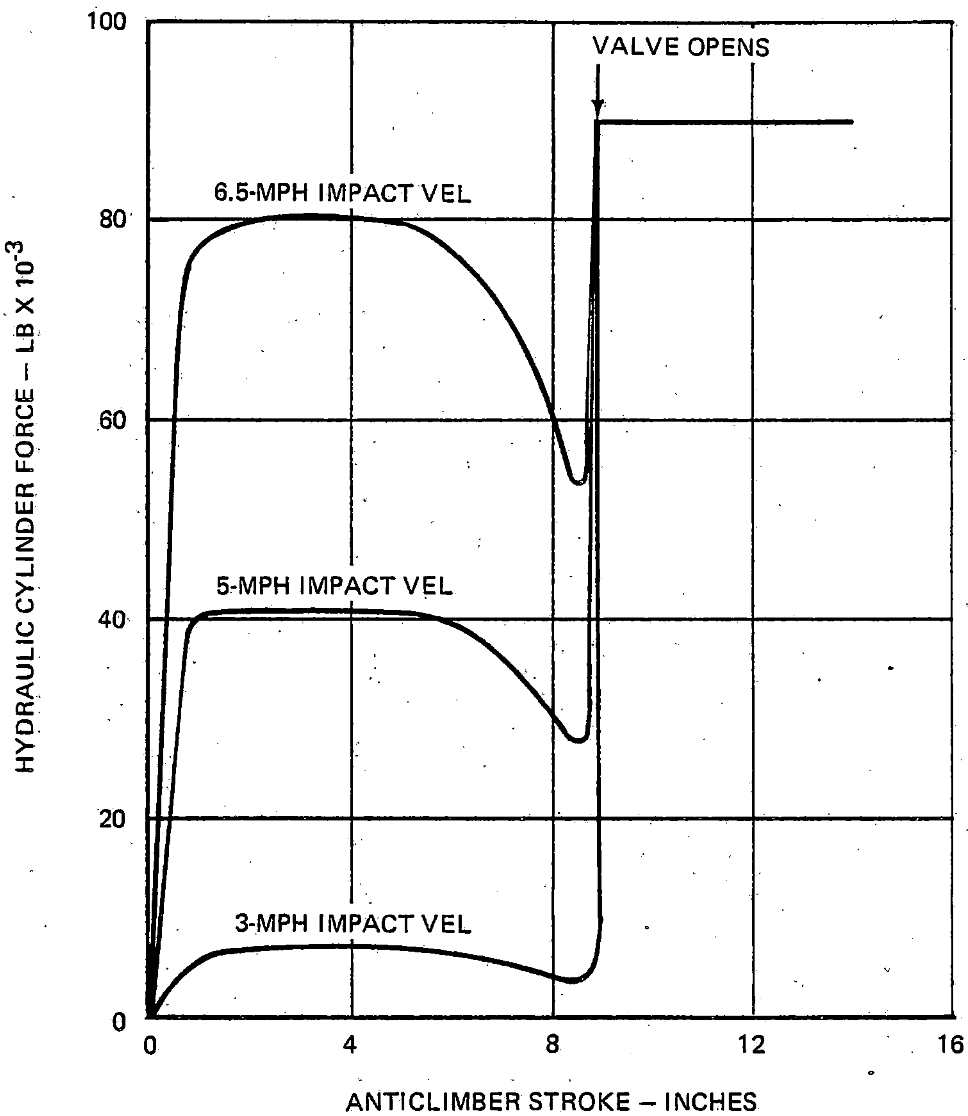


Figure 3–20. Hydraulic Cylinder Force Profile

3.8.2.1 Test Setup

A rigid barrier (proved somewhat resilient) was installed on a section of the north TMB spur as shown in Figure 3-21. The barrier height was selected such that it would mate with the A-end anticlimber yet clear the nose fairing if the anticlimber should move back beyond the forward edge of the carbody nose fairing.

The car was ballasted to the AW0 configuration (approximately 92,000 pounds). The A-end coupler head was removed. The collision attenuation system shear pins were removed for the initial set of tests. A supplemental fluid reservoir was added for test purposes to prevent ingestion of air when the cylinders were stroked as the capacity of the onboard reservoir was insufficient to provide makeup fluid for the volume of cylinder shaft withdrawn during stroking. A seatbelt was installed to restrain the vehicle operator.

The master controller, as built, was unsatisfactory for controlling the 1- to 5-mph speeds required for this test program. A dial potentiometer which limited speed command was added to the control system to provide accurate speed control. A trip wire was added forward of the A truck which could cause a propulsion trip when it impacted a trip post about one foot before impact, as shown in Figure 3-22. The propulsion trip permitted the impact to occur in a true coast mode without power or brake.

3.8.2.2 Instrumentation

The parameters, items 1 through 13 in Table 3-VII, were recorded on a direct-printing oscillograph recorder. Two high-speed (100 frames per second) cameras were located at the impact barrier, one a side view, the other an overhead location looking down, as shown in Figure 3-23. The time code (item 13) was also recorded on the high-speed cameras for correlation of camera and oscillograph data. Appropriate photographic targets were attached to the ACT-1 car to aid in photographic evaluations of displacements and speed data.

3.8.2.3 Pretest Activities

Prior to initiating actual impact testing, it was necessary to verify proper operation of the supplemental fluid reservoir and to check for adequate structural clearances up to the expected maximum stroke (approximately 11 inches).

Initial displacement revealed an interference between the primary structure, 26-31042, and the translating structure, 26-31068-7 plate and -3 angle. The translating structure was cut away locally as required to provide the proper clearance, as shown in Figure 2-12. The supplemental fluid reservoir functioned properly.

Speed calibration runs were made to calibrate the dial potentiometer for the test speeds (1, 1.5, 2.5, and 5 mph). Operation of the propulsion trip wire was verified.

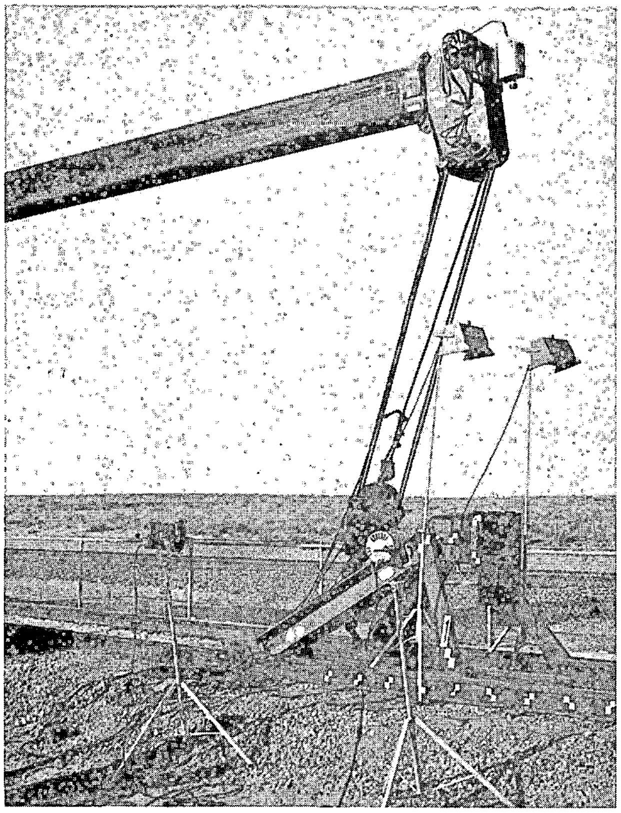


Figure 3–21. Rigid Barrier Installation

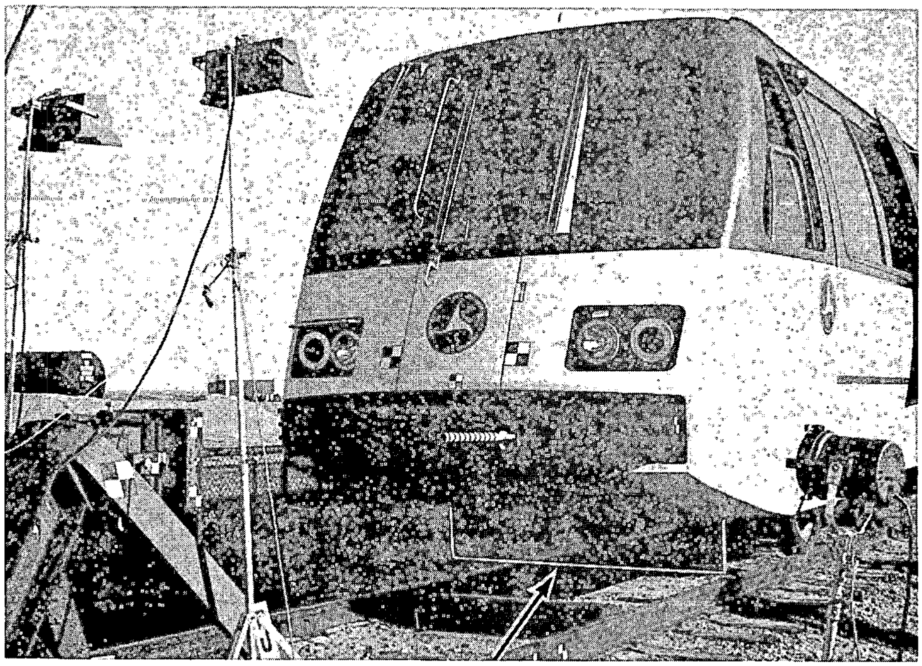


Figure 3–22. Propulsion Trip Wire Installation

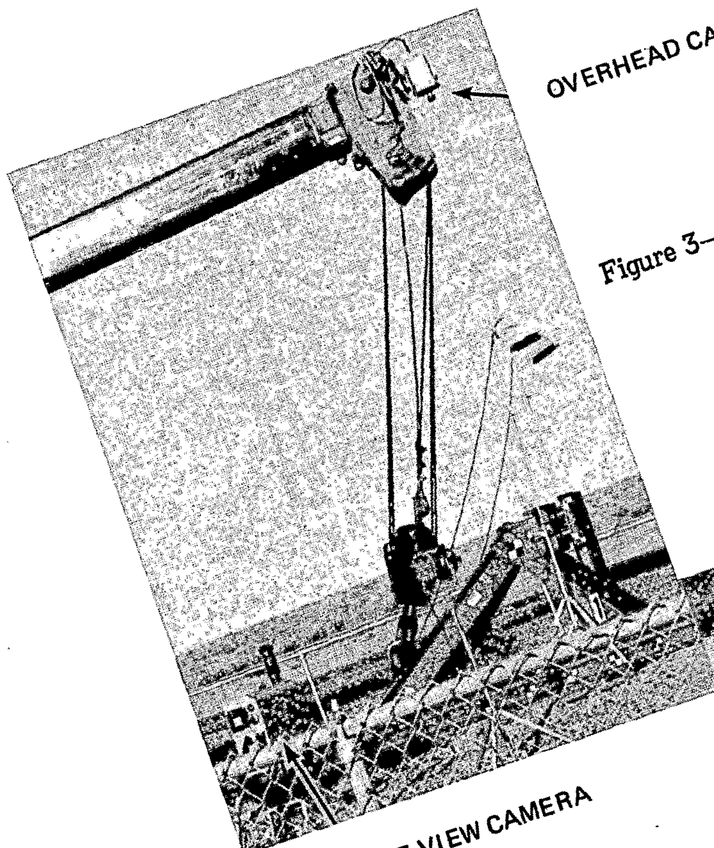


Figure 3–23. High-Speed Camera Locations

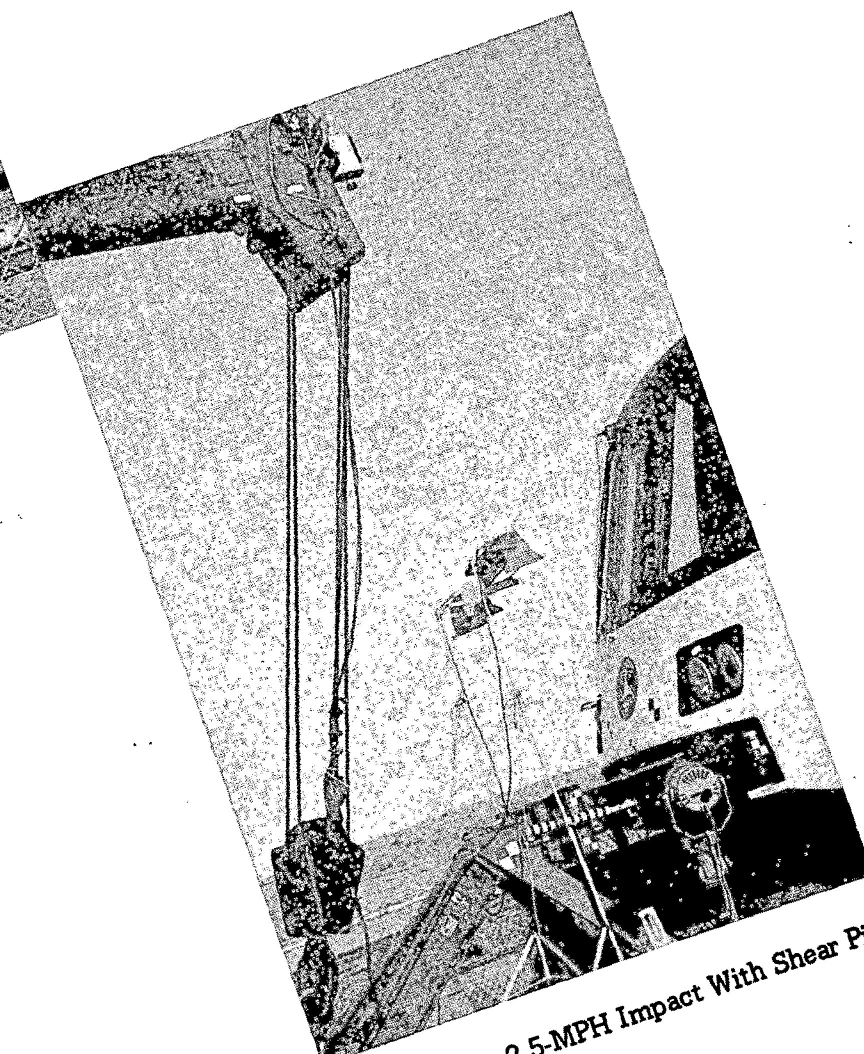


Figure 3–24. 2.5-MPH Impact With Shear Pins

3.8.2.4 Impact Testing

Impact testing was conducted in the sequence outlined in the ACT-1 Special Test Request 003. Impacts without shear pins or the coupler head were conducted at 1, 1.5, 2.5, and 5 mph. The car was powered up by the 600-volt stinger in the TMB. A vehicle operator and a technician were aboard the car during impacts. The ESU's were brought up to approximately 97-percent speed, the stinger was disconnected, and the car was accelerated to test speed by the technician slowly turning the dial potentiometer to the precalibrated value. The oscillograph and cameras were turned on before impact and remained on until the rebound was complete. A quick check of vehicle condition was made, the propulsion trip wire was reconnected, the propulsion system was reset, and the car was driven back into the TMB to reset the collision system.

TABLE 3–VII. COLLISION TEST INSTRUMENTATION

Item	Sensor Location	Priority
1	Anticlimber acceleration, long.	NTH
2	Strut at anticlimber accel, long.	NTH
4	Aft side coupler pivot block accel, long.	NTH
5	Side sill near shear pin, accel, long.	HD
6	Strut near shear pin, accel, long.	HD
7	Car floor accel, long.	RQD
8	Front truck accel, long.	NTH
9	ESU accel, long.	HD
11	Displacement between strut and side sill	RQD
12	Car velocity (ninth wheel)	RQD
13	Time	RQD
14	High-speed motion pictures	RQD

Priority:
RQD – Required for test
HD – Highly desirable but will not hold up test
NTH – Nice to have, low priority

The collision system must be manually returned to the original position in preparation for the next impact speed.

Upon completion of the 1, 1.5, 2.5, and 5-mph impacts without shear pins, the shear pins were installed (coupler head still removed). The car was accelerated to 2.5 mph and impacted the barrier as shown in Figure 3-24 (Run 6). The shear pins did not shear as expected and the oscillograph recorder failed on this run. Lacking realtime data analysis, further testing was suspected until the photographic data could be analyzed. Subsequent analysis of the photographic data revealed a significant deflection of the rigid barrier and undesirable vertical motion of the ACT-1 car. The barrier deflected up to 2 inches at a 5-mph impact and the resultant moment on the track caused the track and car to rise approximately 1 inch. Testing was terminated at this point.

3.8.3 Test Results

A review of the test data from the oscillograph instrumentation revealed the galvanometer response time was too slow to provide meaningful data. Therefore, the photographic data was used exclusively in the data analysis described herein. An overhead and side-viewing camera, as shown in Figure 3-24, recorded 100 frames per second which provided excellent time-history displacement information which was subsequently used for calculating car speed and deceleration rates.

Analytical predictions of collision attenuation system performance without shear pins or the coupler head was compared with the test results. The displacement time history as shown in Figure 3-25 reveals that carbody displacement occurred over a significantly greater period of time than predicted and the resultant displacement was slightly greater. However, the resilience of the rigid barrier attributed to the increased displacement as shown in Figure 3-26. Comparison of the hydraulic cylinder displacements in Figure 3-26 with the predicted displacements of Figure 3-25 shows that the actual stroke of the collision attenuation system was less than predicted. The car-body velocity time histories of Figure 3-27 show a smoother and longer deceleration than predicted..

The most descriptive parameter to describe the collision attenuation system performance is the car deceleration as shown in Figure 3-28. The system as originally designed provided for a very low initial deceleration rate at low impact velocities, with a rather abrupt stop when the internal metering pin becomes ineffective at approximately 9-½ inches displacement. The test data shows the average deceleration rate to be higher and more evenly distributed over a longer time, with a significantly lower peak rate. This provides a much more pleasing deceleration rate for passenger comfort than the abrupt stop as originally designed. It is significant to note that the actual deceleration rates result in lower total hydraulic cylinder displacements at the lower impact speeds, as shown in Figure 3-28, which keep the metering pin effective and avoid the abrupt deceleration when the metering pin becomes ineffective. However, impact velocities greater than 5-mph will still result in deceleration rates of approximately 2 g's.

The design of the hydraulic cylinder did not provide a means of measuring pressure on the high-pressure side of the pistons, so car-body deceleration and cylinder displacement time histories were used to calculate the hydraulic cylinder force as shown in Figure 3-29. The actual force at the lower impact velocities is significantly higher than predicted, which permits the car to come to a stop before the metering pin becomes inactive. The force at the 5.1-mph impact shows an increase in force as the metering pin (tapered) becomes less effective. Figure 3-29 also shows that the metering pin is effective beyond the predicted 9-inch travel.

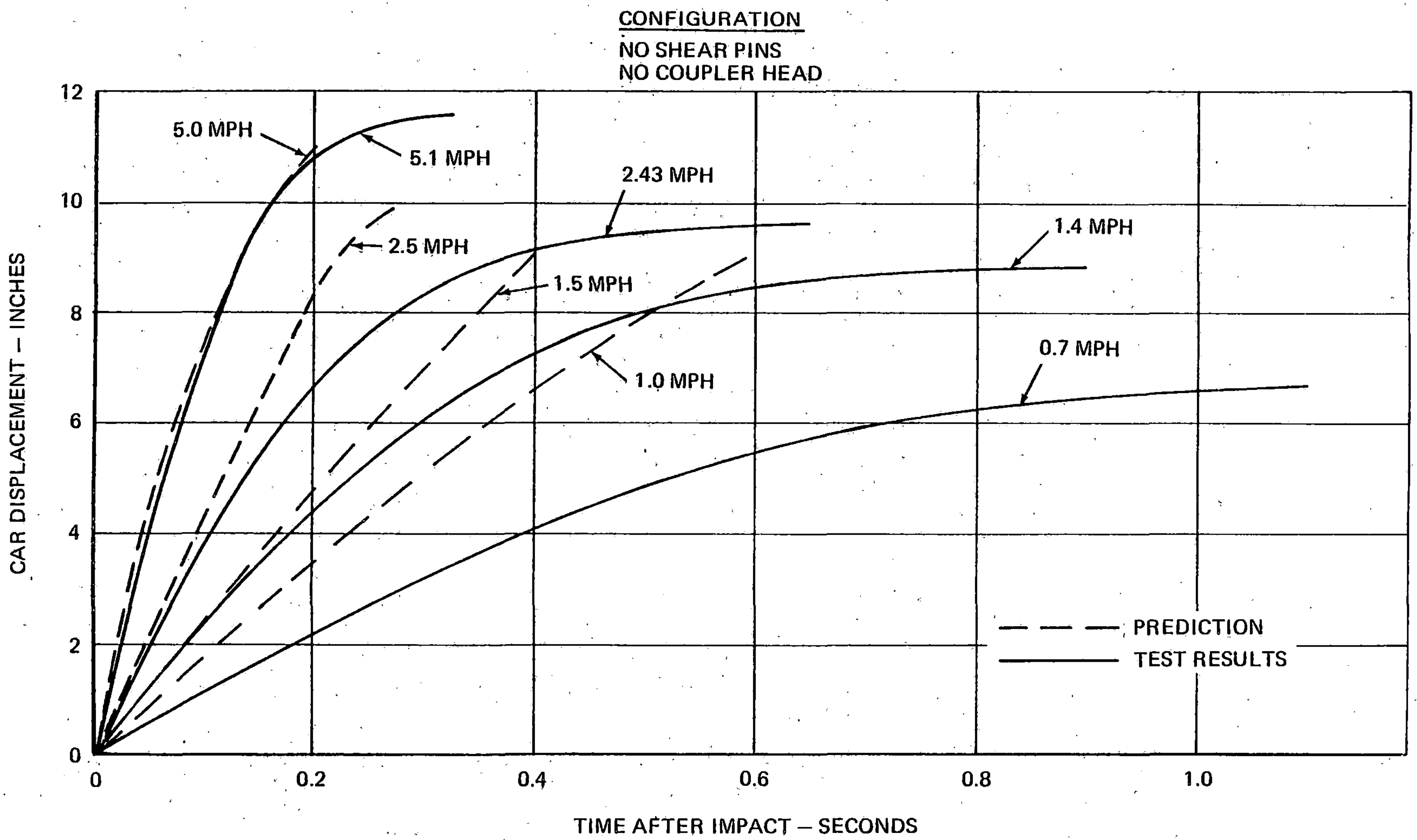


Figure 3–25. Displacement Time History

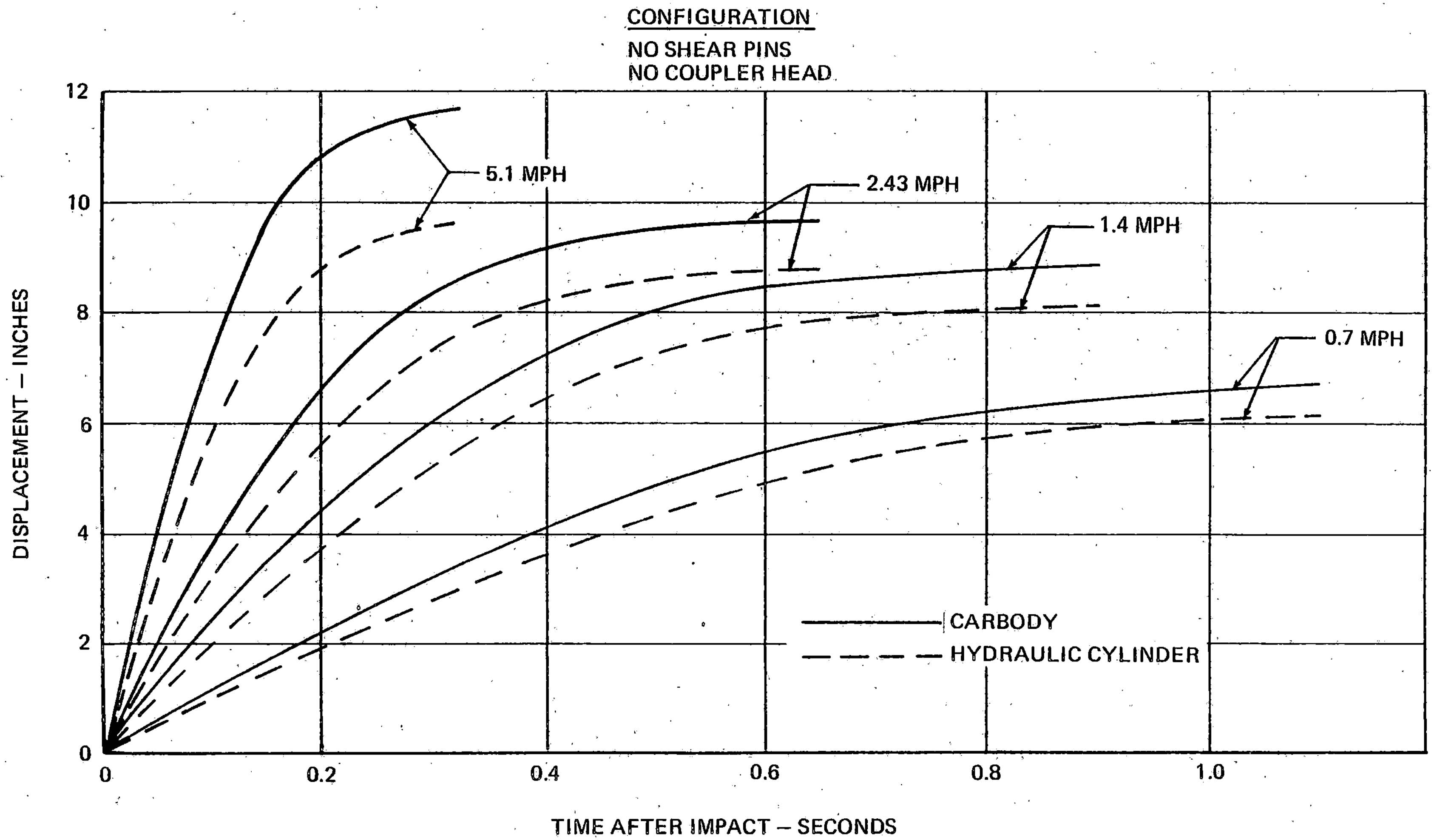


Figure 3–26. Carbody Versus Hydraulic Cylinder Displacement

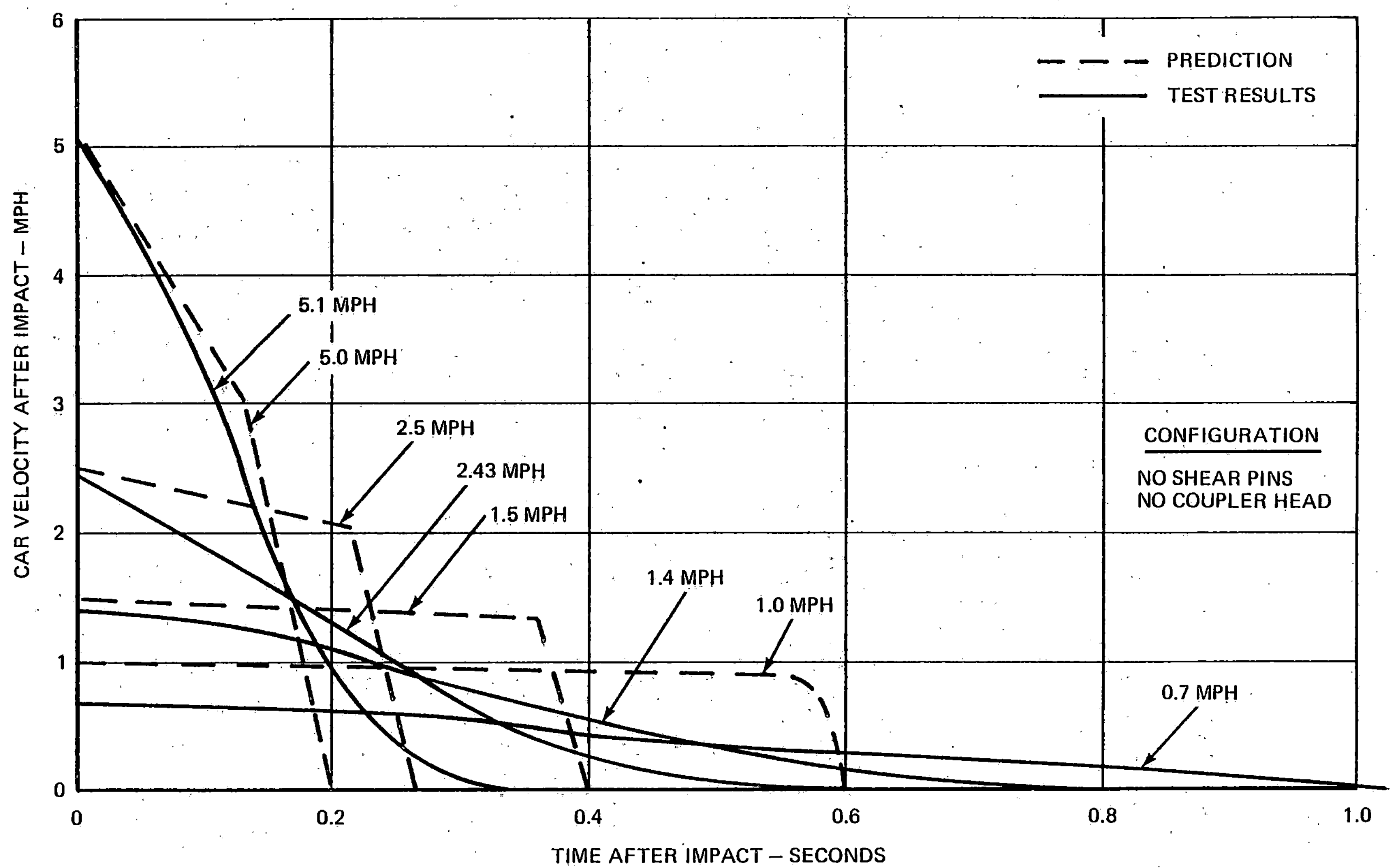


Figure 3–27. Velocity Time History

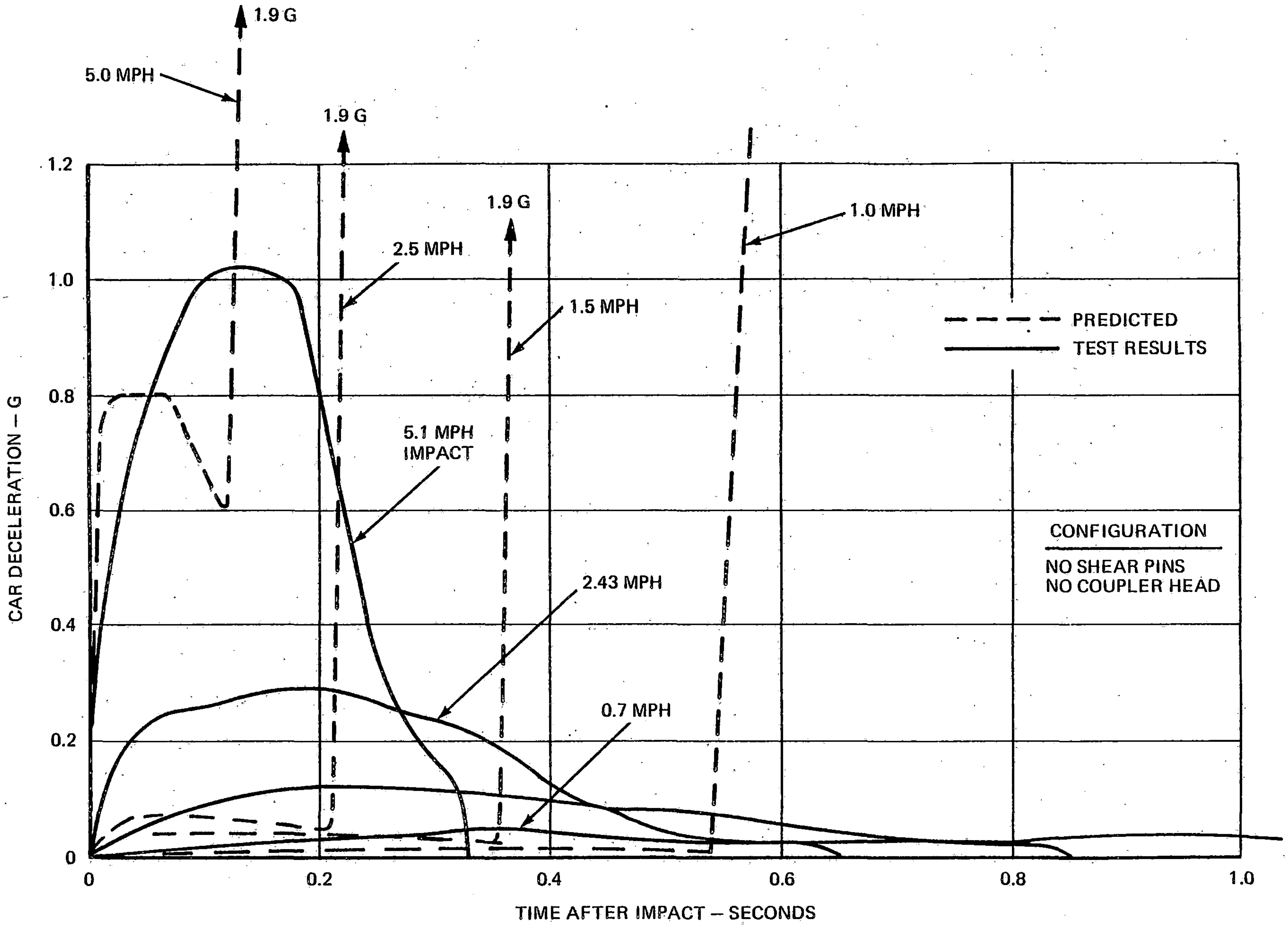


Figure 3–28. Deceleration Time History

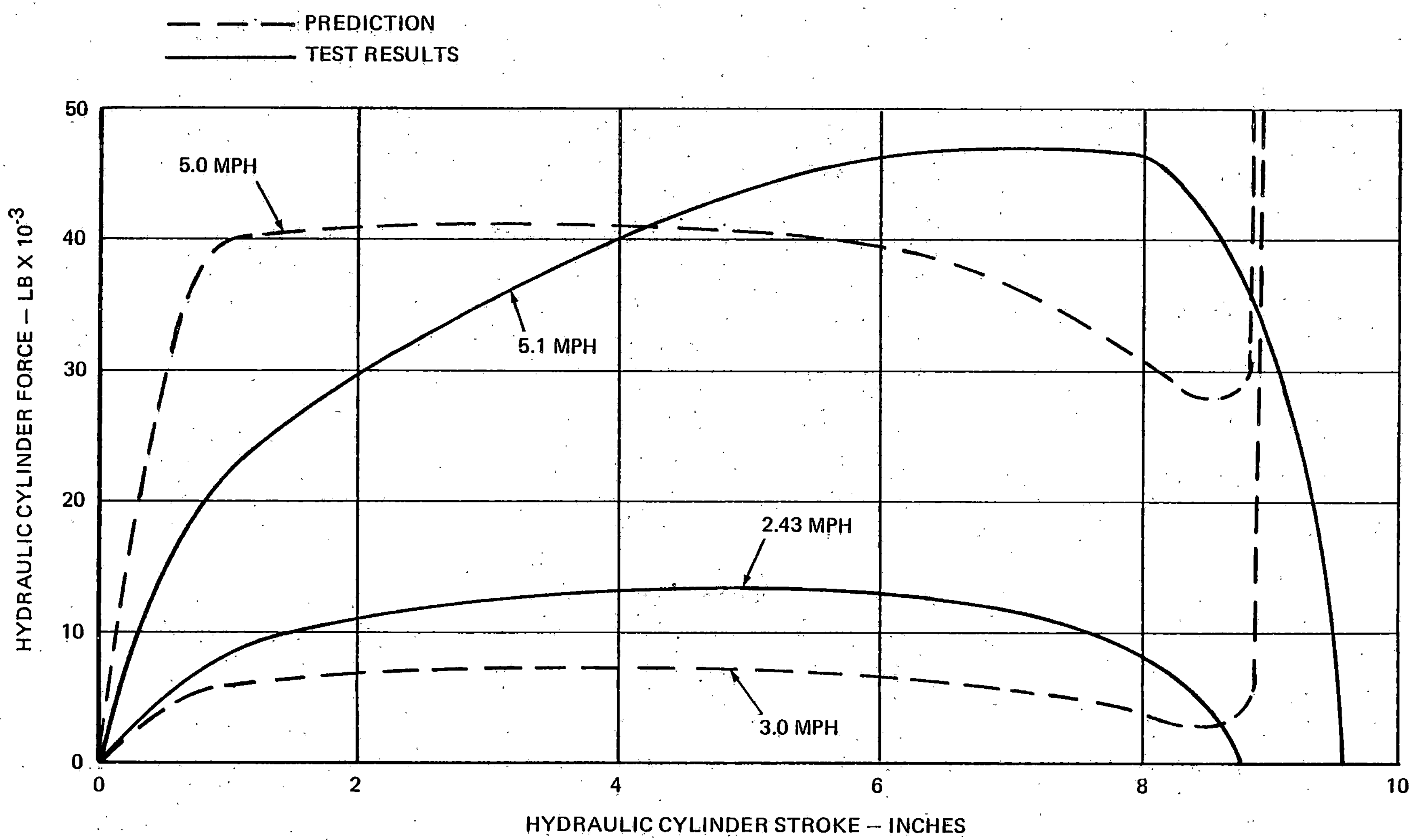


Figure 3–29. Hydraulic Cylinder Force Profile

Upon completion of the described tests, the collision attenuation system shear pins were installed. The coupler head was still removed. The car impacted the barrier at 2.36 mph. The car rebounded from the barrier without shearing the shear pins. Predictions had indicated that the shear pins would fail at slightly over a 1-mph impact into a rigid barrier. Review of the displacement data shown in Figure 3-30 revealed that the rigid barrier had deflected approximately 2.4 inches, which was enough cushioning to prevent the deceleration forces from exceeding the shear pin capability. The shear pins were predicted to fail at approximately a 1.96-g impact and the test data shown in Figure 3-31 indicates that the maximum deceleration attained was approximately 1.7 g's. Examination of the shear pins revealed that they were partially sheared.

Because of the resilience of the rigid barrier, all further testing was cancelled. Sufficient data was obtained to verify collision attenuation system characteristics. It is concluded that the system provides a more gentle deceleration than predicted for impacts of 5 mph or less.

Two design deficiencies were noted: (1) there is inadequate clearance between the movable collision attenuation system hardware and the fixed primary structure to prevent damage at low impact speeds, and (2) the fluid reservoir is undersized and air would be ingested into the cylinders, requiring a major disassembly and purging to restore the system after activation.

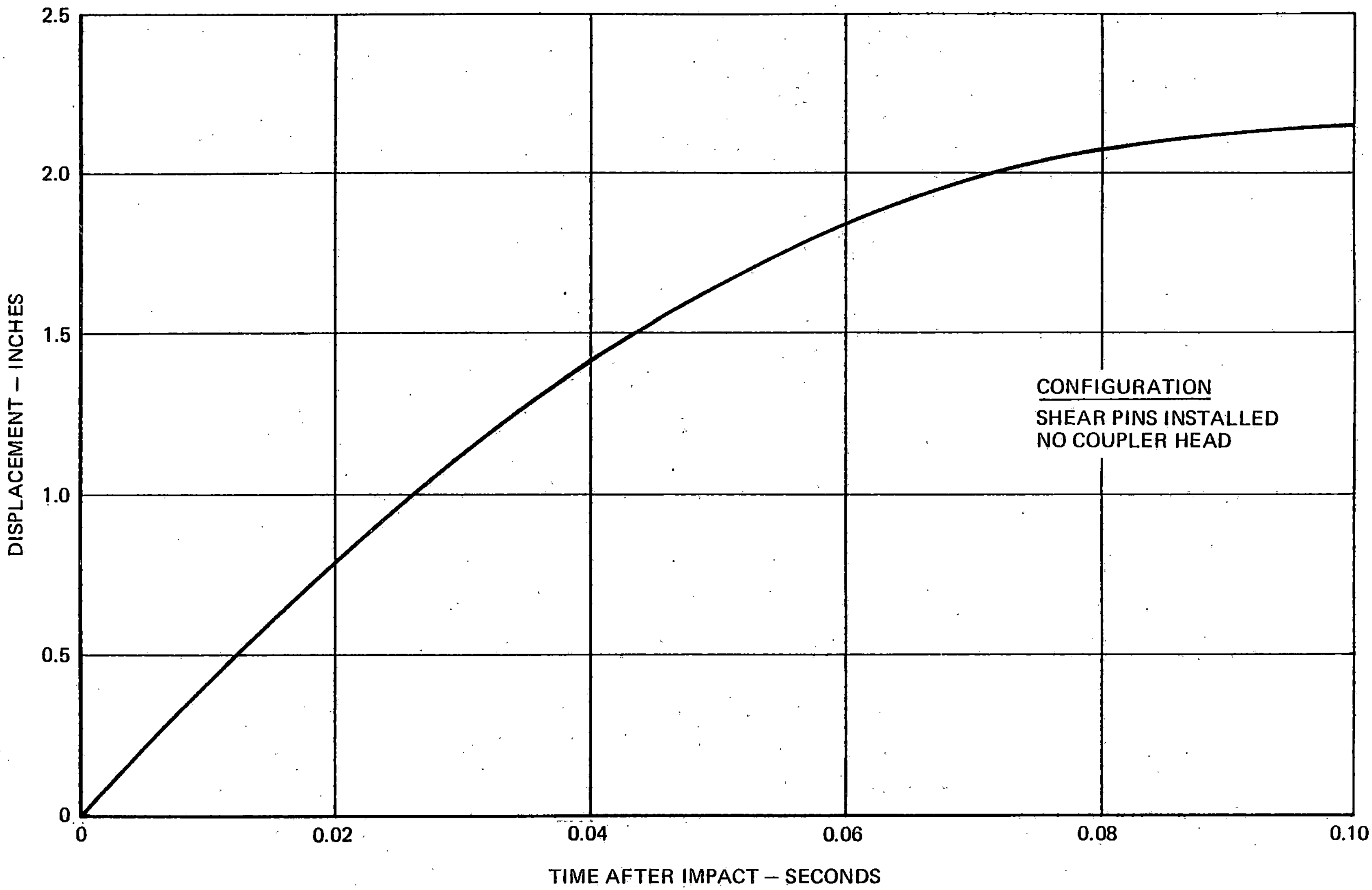


Figure 3–30. Displacement Time History

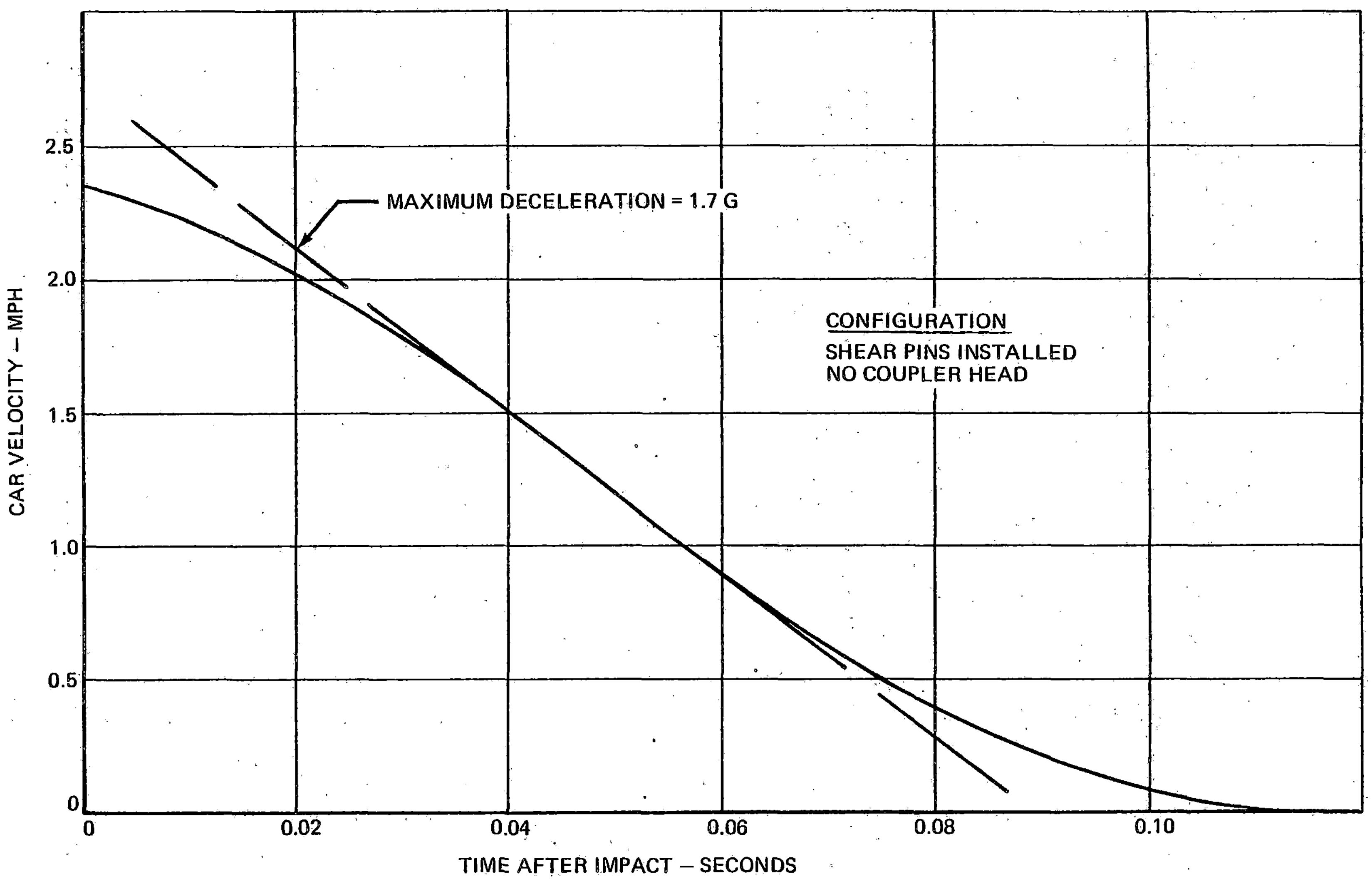


Figure 3–31. Maximum Deceleration

4.0 ENGINEERING PERFORMANCE TESTS

4.1 PERFORMANCE SUMMARY

The performance characteristics of the ACT-1 vehicles were determined during engineering tests to verify compliance with specification requirements and goals. Table 4-I provides a summary of the DOTX-5 acceptance test performance which is typical for both cars. Performance data is provided in this section for single-car operation at weights AW1 (98,000 pounds) and AW3 (130,400 pounds). Two-car train performance data is limited to the AW1 configuration. Significant variations from the specification performance are discussed below.

The acceleration performance meets all of the specification requirements except that the initial acceleration rate exceeds the nominal value by more than 5 percent for some runs. The acceleration and deceleration levels are proportional to the control input level throughout the control range.

The automatic speed regulation system holds the speed within ± 2 mph of the selected speed over grades up to ± 1.5 percent in all but a few runs.

A few problems are evident in the braking performance data. There is an initial overshoot in deceleration rate for most braking runs. For blended-braking stops from approximately 70 mph and higher, the energy that has to be stored by the ESU is great enough that the ESU reaches its maximum speed before the car is stopped. When the ESU reaches its maximum speed, electric braking cannot be maintained and the friction brakes do not blend in soon enough to keep the deceleration rate from momentarily dipping down to a relatively low value. The emergency-braking rate varies considerably with car speed, which results in a large maximum or minimum excursion in deceleration rate, depending upon the initial car speed.

The braking rate for a 130,400-pound gross weight is generally 0.2 mphps less than for a 98,000-pound gross weight. The two-car train acceleration and deceleration performance is the same as that of the individual cars.

DOTX-4 initially met the specification requirements for control response deadtime in nearly all cases. Subsequent configuration changes appear to have substantially increased the deadtime. The DOTX-5 deadtime is greater than the specified maximum in most cases. Although the electric braking deadtime exceeds the specified maximum for transitions to blended braking, the friction brakes are applied initially so that the vehicle deceleration response time is kept reasonably short. With just a few exceptions, the control response jerk rate meets the specification requirement.

The continuous duty cycle with two consecutive counterclockwise runs from station 0 to A was found to be more severe than the duty cycle consisting of five consecutive emergency stops from 80 mph. The maximum recorded brake-lining temperature measured was 935°F, which compares to a lining thermal limit of 750°F. However, the lining was still serviceable after occasionally brief exposure to temperatures up to 1,050°F. Conducting the continuous

TABLE 4–I. DOTX-5 ACCEPTANCE TEST RESULTS

TEST	WEIGHT	SPEED	COMMAND "P" WIRE PERCENT	THIRD RAIL VOLTAGE VOLTS	SPECIFICATION PARAGRAPH	SPECIFICATION LIMITS	TEST RESULTS
Acceleration	AW1	0-80	100%	560	2.2.2.3		
					Nominal-MPHPS	3.0	3.0
					Maximum Excursion-MPHPS	± 0.2	-.09
					Maximum Average Deviation-Percent	± 5%	+1.7%
					Distance in 20 Sec-Min Feet	700	730
					Time to 80 MPH-Sec	52	53
					Distance to 80 MPH-Max Feet	3800	3922
					Jerk Rate-MPHPSPS	2.0	2.1
					Dead Time-Sec	0.5	0.7
	AW3	0-80	100%		Nominal	Not Specified	2.43
					Distance in 20 Sec-Feet	Not Specified	573.
					Time to 80 MPH-Sec	Not Specified	88
Blended Braking	AW1	80-0	100%	N/A	2.2.4.1		
					Nominal-MPHPS	3.0	3.0
					Maximum Excursion-MPHPS	± 0.3	-.39
					Maximum Average-5 Sec Deviation-Percent	±7%	8.0 %
					Jerk Rate-MPHPSPS	2.0	2.57
					Dead Time-Sec	0.5	0.1

TABLE 4–I – Continued

TEST	WEIGHT	SPEED	COMMAND "P" WIRE PERCENT	THIRD RAIL VOLTAGE VOLTS	SPECIFICATION PARAGRAPH	SPECIFICATION LIMITS	TEST RESULTS
Blended Braking (Continued)							
	AW3	80-0	100%	N/A	Nominal-MPHPS	3.0	3.0
					Maximum Excursion-MPHPS	±0.3	-.49
					Maximum Average-5 Second Deviation - Percent	±7%	13%
					Jerk Rate-MPHPSPS	2.0	1.9
					Dead Time - Sec	0.5	0.3
	AW3	40-0	100%	N/A	Nominal-MPHPS	3.0	3.0
					Maximum Excursion-MPHPS	±0.3	-.31
					Maximum Average-5 Second Deviation - Percent	±7%	+10.2%
					Jerk Rate - MPHPSPS	2.0	3.2
					Dead Time - Second	0.5	0.4
					Average Acceleration-MPHPS	2.7	2.7
Friction Braking	AW1	80-0	100%	N/A	2.2.4		
					Nominal-MPHPS	3.0	3.0
					Maximum Excursion-MPHPS	±0.3	-.26
					Maximum Avg Deviation-Percent	±7%	6.1%
					Jerk Rate-MPHPSPS	2.0	2.4
					Dead Time - Second	0.5	0.1

TABLE 4–I -

TEST	WEIGHT	SPEED	COMMAND "P" WIRE PERCENT	THIRD RAIL VOLTAGE VOLTS
Friction Braking (Continued)				
	AW1	40-0	100%	N/A
	AW3	80-0	100%	N/A
	AW3	40-0	100%	N/A

– Continued

SPECIFICATION PARAGRAPH	SPECIFICATION LIMITS	TEST RESULTS
2.2.4		
Nominal-MPHPS	3.0	3.0
Maximum Excursion-MPHPS	±.3	-.21
Maximum Avg-5 Second Deviation - Percent	±7%	8.3%
Jerk Rate - MPHPSPS		3.0
Dead Time - Second		0.1
Nominal-MPHPS	3.0	3.0
Maximum Excursion-MPHPS	±0.3	.23
Maximum Avg-5 Second Deviation - Percent	±7%	±9%
Average Deceleration-MPHPS	2.7	3.06
Jerk Rate - MPHPSPS	2.0	2.4
Dead Time - Sec	0.5	0.1
Nominal - MPHPS	3.0	3.0
Maximum Excursion - MPHPS	±0.3	±.75
Maximum Avg Deviation-Percent	±7%	20%
Average Deceleration - MPHPS	2.5	
Jerk Rate - MPHPSPS	2.0	2.25
Dead Time - Second	0.5	0.1

TABLE 4–I – Continued

TEST	WEIGHT	SPEED	COMMAND "P" WIRE PERCENT	THIRD RAIL VOLTAGE VOLTS	SPECIFICATION PARAGRAPH	SPECIFICATION LIMITS	TEST RESULTS
Emergency Braking	AW1	80-0		N/A	2.2.4.2		
					Nominal-MPHPS	3.5	3.5
					Maximum Excursion - MPHPS	±0.30	+.26
	AW1	40-0			Nominal - MPHPS	3.5	3.22
					Maximum Excursion - MPHPS	±0.3	-.44
	AW3	80-0	Deadman		Nominal - MPHPS	3.5	2.84
					Maximum Excursion - MPHPS	±0.30	-.85
					Average Deceleration-Min MPHPS	3.3	2.66

duty cycle with two consecutive counterclockwise runs may have been more severe than with alternate counterclockwise (station 0 to A) and clockwise (station A to 0) runs. To preclude the possibility of exceeding thermal limits, the continuous duty cycle with friction braking was not repeated to ascertain the effects of performing an emergency stop from 80 mph immediately following the station stop that resulted in the highest brake-lining temperature.

In general, the drift test results, although limited, confirm levels of train resistance used in performance predictions that were estimated based on the modified Davis equations.

A comparison of continuous-duty-cycle performance with blended and friction-only braking on the ACT-1 synthetic transit route indicates that the energy storage unit (ESU) provides a 48.6-percent energy savings with respect to an operational mode of the ACT-1 vehicles in which kinetic energy during braking is not recovered. For normal operation the ACT-1 vehicle, in a two-car train consist on a round trip of the ACT-1 synthetic transit route, exhibits 7.12 kw-hr/cm energy consumption.

To be considered in evaluating ACT-1 total energy consumption requirements are 21.0-kw-hr energy consumption to attain idle boost speed of the ESU at startup and 50-kw power to maintain idle boost speed at any layover. For example, on the basis of only one round trip with a 3-minute turnaround time, the total ACT-1 vehicle energy consumption is estimated to be 155.22 kw-hr or 8.39 kw-hr/cm. As reported in UMTA-IT-06-0026-74-1, SOAC Development Program, the corresponding SOAC energy consumption is 12.43 kw-hr/cm. Note that on layovers in excess of 25 minutes, the energy consumed during startup (21 kw) is less than maintaining idle boost; therefore, it pays to shut down the ESU instead of maintaining idle boost speed.

For the short-duration, maximum-capability duty cycle the rms traction motor armature current is 584.5 amperes.

Acceleration and deceleration tests at high and low rates were conducted while traversing a power-isolation gap. These runs were made with and without third rail enable. The no-third-rail-enable switch, when energized, permits continued operation in parallel offline drive mode using the available energy stored in the flywheel. When the third rail enable is deenergized, the propulsion control system commands a vehicle stop with a jerk-limited deceleration rate in response to a loss in power source. Test results confirmed that vehicle performance during braking and parallel offline drive conditions are unaffected by the power-isolation gap encountered. During parallel online drive condition, performance is partially interruped in the power-isolation gap. Performance is completely interrupted in the power-isolation gap during series drive mode. Possibly due to the short length of power-isolation gap, which was traversed in 1.5 to 3.0 seconds depending on gap entry conditions, the effect of the third-rail-enable switch was not clearly discernible.

In general, slip-spin efficiency and slip-slide efficiencies as measured in acceleration and deceleration conditions, respectively, fall short of specification requirements. Based on subjective evaluations made on board the vehicle during these tests and under wet or icy rail conditions in which the spin-slide system was functioning, vehicle ride quality did not deteriorate appreciably.

4.2 TEST OBJECTIVE

The test objectives of the ACT-1 engineering performance test program are as follows:

- To determine the acceleration and deceleration characteristics of the ACT-1 vehicles using drive, blended braking, friction braking, electric braking, and emergency braking operating modes; as affected by car direction, train consist, control input, energy storage unit (ESU) speed, and line voltage. Also, to verify that performance satisfies design goals and requirements.

- To demonstrate that the ACT-1 vehicle's speed regulation systems maintain car speed at the preselected value.

- To determine the deadtime and jerk-rate control response characteristics of the ACT-1 vehicles in transitioning from one operating mode to another.

- To determine the traction (train) resistance of the ACT-1 vehicles for comparison with Davis equation coefficients used for estimation of vehicle performance.

- To determine the continuous duty-cycle characteristics of the ACT-1 vehicles. Specifically, to establish energy consumption associated with the energy storage units, rms armature current values of the traction motors, and vehicle schedule performance.

- To determine the short-duration maximum-capability duty-cycle characteristics of the ACT-1 vehicles. In particular, to demonstrate satisfactory equipment temperatures and establish rms armature current of the traction motor for conditions of limiting thermal performance.

- To determine the friction brake duty-cycle characteristics of the ACT-1 vehicles and substantiate the friction brake's thermal capacity.

- To determine the power-isolation-gap performance characteristics of the ACT-1 vehicle.

- To determine the acceleration and deceleration characteristics of the ACT-1 vehicles while operating under the control of the spin/slide protective system during simulated adverse rail adhesion conditions. Specifically, to establish slip-spin efficiency in acceleration and slip-slide efficiencies during deceleration modes.

4.3 TEST DESCRIPTION

A general description of the way in which tests were conducted follows.

4.3.1 Acceleration

To achieve partial- and full-service acceleration performance, the ACT-1 vehicles were accelerated on level tangent track to maximum achievable speed by advancing the master controller from full-service brake to drive position. Tests were conducted in forward and reverse directions over the same section of track at various master controller drive positions. Test conditions included AW1 (98,000 pounds) and AW3 (130,400 pounds) car weights; nominal (600 volts), high, and low levels of line voltage; 98, 88, and 75-percent initial energy storage unit (ESU) flywheel speed; DOTX-4 and DOTX-5 ACT-1 vehicles tested singly and in a two-car train consist.

4.3.2 Deceleration

To achieve partial- and full-service deceleration performance in blended, friction, electric, and emergency-braking modes, the ACT-1 vehicles were decelerated from selected brake entry speeds of 20, 40, 60, 70, and 80 mph to a complete stop by retracting the master controller from coast to brake position. Friction-braking condition was established by temporarily disabling the electric brakes, whereas electric braking was established by temporarily disabling friction brakes. Tests were conducted in forward and reverse directions over the same section of track at various master controller brake positions. For emergency braking the deadman switch and the emergency pushbutton were also activated. Test conditions included AW1 (98,000 pounds) and AW3 (130,400 pounds) car weights; DOTX-4 and DOTX-5 ACT-1 vehicles tested singly and in a two-car train consist.

4.3.3 Speed Regulations

To demonstrate automatic speed regulation capability, the ACT-1 vehicles were operated in automatic speed regulation mode at the selected control speeds of 3, 15, 25, 35, 50, 60, 70, and 80 mph. Tests were conducted in forward and reverse directions on track segments having positive grades. Test conditions included AW1 (98,000 pounds) car weight and DOTX-4 and DOTX-5 ACT-1 vehicles tested singly and in a two-car train consist.

4.3.4 Control Response

To establish control response deadtime and jerk-rate characteristics, the ACT-1 vehicles were operated so as to transition from one mode of operation to another and modulate within a mode of operation by power sequencing of the master controller. Test conditions included AW1 (98,000 pounds) and AW3 (130,400 pounds) car weights and DOTX-4 and DOTX-5 ACT-1 vehicles tested singly and in a two-car train consist.

4.3.5 Drift Tests

To acquire drift characteristics, the ACT-1 vehicle was operated in coast on level tangent track over a 70-10-mph speed range. To establish a true coast condition, both propulsion and friction braking systems were disabled upon attainment of initial speed. Test conditions included AW1 (98,000 pounds) car weight and DOTX-4 ACT-1 vehicle.

4.3.6 Duty-Cycle Performance

A continuous duty cycle and a short-duration, maximum-capability duty cycle that were used in design were employed for evaluation of the ACT-1 vehicles in test. The continuous duty cycle served as a basis for establishing energy consumption, rms values of traction motor armature and field currents, and schedule performance. The continuous duty cycle consisted of a synthetic transit route of 28 station stops in a round trip. Limit speeds between stations varied from 40 to 80 mph. The ACT-1 vehicles were accelerated from stop at each station using full-service acceleration until limit speed was attained. Limit speed was maintained until it was necessary to decelerate, using full-service blended braking, to a stop at each station. For simulated station dwells of 20 seconds, the round trip was intended to be completed within 39 minutes schedule time without turnaround time. The turnaround-time allowance at the end of the round trip is 3 minutes.

The short-duration, maximum-capability duty cycle served as a basis for establishing limiting values of rms values of traction motor armature currents and equipment temperatures. This duty cycle consisted of 15 minutes of repetitive operation of the following profile on level tangent track: maximum acceleration to 80 mph followed immediately by full-service blended braking to a stop, with a simulated 20-second station dwell.

Test conditions included AW1 (98,000 pounds) car weight, DOTX-4 and DOTX-5 ACT-1 vehicles tested singly and in a two-car train.

4.3.7 Friction Brake Duty Cycles

To demonstrate adequate friction brake thermal capacity the DOTX-5 ACT-1 vehicle, at AW1 (98,000 pounds) car weight, was operated per the continuous duty cycle above but with full-service friction braking only in lieu of blended braking. Another deviation from the standard continuous duty cycle was to conduct two consecutive counterclockwise trips instead of one clockwise and then, on the return trip, one counterclockwise trip for a completed round trip.

To further evaluate friction brake thermal capacity, five consecutive emergency stops within a 15-minute period from an 80-mph entry speed were performed with the DOTX-5 ACT-1 vehicle, at AW3 (130,400 pounds) car weight. The 15-minute period, inclusive of acceleration and braking intervals, included periods of constant-speed running at 80 mph but no station dwell time.

4.3.8 Power-Isolation-Gap Performance

To define power-isolation-gap performance characteristics the DOTX-4 ACT-1 vehicle at AW1 (98,000 pounds) car weight was accelerated, decelerated, and operated at constant speeds through a power-isolation gap on the third rail.

4.3.9 Slip-Spin Acceleration

To establish slip-spin performance capability, the ACT-1 vehicle was driven from start at zero speed at full-service acceleration command through a segment of track having artificially lowered rolling resistance. Tests were conducted with the DOTX-5 ACT-1 vehicle at AW1 (98,000 pounds) car weight in a forward direction.

4.3.10 Slip-Slide Deceleration

To define slip-slide performance characteristics in blended, friction, and emergency-braking modes, the ACT-1 vehicle was decelerated from various entry speeds through a segment of track having artificially reduced rolling resistance. Tests were conducted with the DOTX-5 ACT-1 vehicle at AW1 (98,000 pounds) car weight in a forward direction.

4.4 TEST INSTRUMENTATION

The ACT-1 instrumentation system recorded parameters that define the performance and operational characteristics of the ACT-1 vehicle, the ACT-1 vehicle's propulsion and braking systems, carbody equipment, and the power distribution system. The performance parameters recorded on magnetic tape are identified in Table 4-II. Brake-lining and equipment temperatures were recorded on chart recorders during duty-cycle testing. Energy consumption and rms armature and field currents of the traction motors were established by computer analysis of the variation with time of voltage and currents, as well as by measurements of special meters on the car. For further details of the ACT-1 instrumentation system refer to the appendix.

4.5 TEST PROCEDURES

The detailed test procedures used for the ACT-1 performance testing were essentially as defined by "General Vehicle Test Plan (GVTP) for Urban Rail Transit Cars", UMTA-MA-06-0025-75-14. The basic GVTP's have been modified for the purposes of this test program to reflect the unique characteristics and requirements of the ACT-1 vehicles. Tabulated below are the test procedure set numbers associated with each of the specific performance areas:

Acceleration		P-2001-TT
Speed Regulation		P-5030-TT
Deceleration	– Blended Braking	P-3001-TT
	– Service Friction	P-3002-TT

TABLE 4–II. PERFORMANCE INSTRUMENTATION MAGNETIC TAPE RECORDS

CODE	PARAMETER	R CAL	R CAL EQUIV. ENG.UNITS	TAPE RECORDER
	VOLTAGE			
104	Fwd ESU Armature Voltage	5 VDC	1500 VDC	B
105	Aft ESU Armature Voltage	5 VDC	1500 VDC	
106	Traction Motor 'A' Armature Voltage	5 VDC	1500 VDC	
107	Traction Motor 'B' Armature Voltage	5 VDC	1500 VDC	
108	Third Rail Voltage	5 VDC	1000 VDC	A
109	Aft E. P. Dyn. Brake Feedback Signal	5 VDC	100% @ AW3	B
110	Propulsion System Drive Trainline	ON/OFF		
111	Fwd E.P. Dyn. Brake Feedback Signal	5 VDC	100% @ AW3	
	CURRENT			
201	Third Rail Current	-5V	2000A	A
202	Traction Motor 'A' Armature Current	±1V	± 1000A	A
203	Traction Motor 'B' Armature Current	±1V	± 1000A	A
204	Traction Motor 'A' Field Current	±1V	± 50A	A
205	Traction Motor 'B' Field Current	±1V	± 50A	A
206	Fwd ESU Armature Current	±1V	± 1000A	B
207	Aft ESU Armature Current	±1V	± 1000A	B
208	Fwd ESU Field Current	±1V	± 50A	B
209	Aft ESU Field Current	±1V	± 50A	B
210	P Signal	D.C. Analog		A
214	Trk A E.P. Valve Converter	5V	250 MA	B
215	Trk B E.P. Valve Converter	5V	250 MA	B

TABLE 4–II –

CODE	PARAMETER
	<u>RPM/SPEED/DISTANCE</u>
301	Car Speed
302	Car Distance
303	Fwd ESU Speed
304	Aft ESU Speed
305	Traction Motor 'A' Speed
306	Traction Motor 'B' Speed
	<u>PRESSURE</u>
501	Truck A-Brake Actuator
502	Truck B-Brake Actuator
	<u>ACCELERATION</u>
741	Car Body C/L Floor Sta 491-Longitudinal
	TIME (IRIG B)

- Continued

R CAL	R CAL EQUIV. ENG. UNITS	TAPE RECORDER
1173.33 HZ	80 MPH	A
1 pulse	0.1 Ft	A
5V	100%	B
5V	100%	B
5V	100 MPH	B
5V	100 MPH	B
1V	100 PSI	A
IV	100 PSI	A
5V	$\pm$ 0.25G	A
		A & B

	– Friction Duty Cycle	P-5012-TT
	– Electric	P-3003-TT
	– Emergency	P-3004-TT
Control Response		P-5020-TT
Drift Test		P-4001-TT
Power Consumption		PC-5011-TT
Thermal Duty Cycle		P-6003-TT
Power Isolation Gap		P-5050-TT
Slip/Spin Acceleration		P-2011-TT
Slip/Slide Deceleration		P-3011-TT

4.6 TEST RESULTS

4.6.1 Acceleration

The acceleration performance for various control input and line voltage levels with a 98,000-pound car weight is presented in Figures 4-1 through 4-7. Two-car train performance is shown in Figures 4-8 and 4-9.

The ACT-1 meets the specification requirements for acceleration with perhaps one exception. While the average initial acceleration with a full control input remains within 5 percent of the nominal 3.0 mphps value for most runs, it slightly exceeds 3.0 mphps plus 5 percent for some runs. It can be seen from the time history in Figure 4-1 that the car achieves a speed of 84 mph, which meets the requirement of 80 mph. Figure 4-2 shows that 80 mph is reached in 49 seconds (52 seconds required) while traveling a distance of 3,750 feet (3,800 feet required). The distance traveled in 20 seconds is 764 feet (700 feet required). From Figure 4-4 it is seen that the initial acceleration level is held to a speed of at least 30 mph as required by the specification. While the car's balance speed was not measured on a 2.75-percent adverse grade, it can be seen from Figure 4-4 that the acceleration rate at 72 mph is 1.05 mphps, which is greater than the 0.56 mphps required to maintain speed on a 2.75-percent grade.

During initial acceleration up to approximately 40 mph, power is obtained from the ESU and the performance is essentially independent of line voltage level. After the system switches online, the performance is dependent upon the line voltage level. This offline/online characteristic can be seen in Figures 4-3 and 4-5.

Figure 4-6 shows that the acceleration level is proportional to the control input level throughout the control range.

4.6.2 Speed Regulation

The automatic speed regulation performance for DOTX-4, DOTX-5, and a two-car train is presented in Figures 4-10 through 4-12. Runs were performed to evaluate the speed-regulation capability at each of the specified speeds. The maximum and minimum car speed excursions during each run are shown as a function of the selected speed. The runs were performed on various grades up to ± 1.5 percent, which is the maximum grade on the UMTA rail transit test track.

It can be seen from Figures 4-10 through 4-12 that the car speed is held generally within ± 2 mph of the selected speed, which slightly exceeds the specified maximum of ± 1.5 mph. The magnitude of the maximum and minimum excursions appears to be independent of the magnitude of the selected speed. The speed regulation performance is essentially the same for both cars and the two-car train.

In general, the accuracy of speed maintenance is influenced by grade. However, no specific relationship such as car speed deviation with grade is established since the magnitudes of the grades investigated were small.

4.6.3 Deceleration in Blended Braking

The blended braking performance for various initial car speeds, car weights, and control input levels is presented in Figures 4-13 through 4-23. Two-car train performance is shown in Figures 4-24 and 4-25.

A time history for a blended-braking stop from 80 mph is shown in Figure 4-13. There is an initial overshoot in deceleration rate due to a large inshot of friction brakes. The energy that has to be stored by the ESU for a stop from 80 mph is large enough that the ESU reaches its maximum speed well before the car is stopped. It can be seen that the friction brakes do not blend in soon enough to keep the deceleration rate from dropping down. In Figure 4-14 the initial car speed is 58.3 mph. The ESU does not reach its maximum speed in this case, so the electric braking can be maintained and a dip in deceleration rate does not occur. However, the friction-brake blend when the electric braking fades causes some excursion in the deceleration rate at the end of the run.

Deceleration rate average values and maximum excursions as a function of initial car speed are shown in Figure 4-15; the specification requirements for blended braking are indicated. The initial overshoot in deceleration rate and the blending transients result in maximum and minimum excursions, respectively, that exceed the specified limits. It can be seen that for stops from 60 mph and less, the minimum excursion is well within the specified limit until the electric brakes fade at approximately 2 mph. The average deceleration rate decreases slightly at the lower initial car speeds. In Figure 4-16 the average deceleration rates and maximum excursions for the 130,400-pound car are presented. While the characteristics are similar to those of the 98,000-pound car, the average deceleration rate is approximately 0.2 mphps lower than for the 98,000-pound car weight.

The required time and distance to stop as a function of initial car speed and control input level are shown in Figure 4-17. For a full-service-braking control input and 98,000-pound car weight, the stopping time and distance from an initial car speed of 80 mph are 28.2 seconds and 1,710 feet, respectively.

Deceleration rate/speed profiles for various control input levels and initial car speeds are shown in Figures 4-18 through 4-21. Except for the initial overshoot and blending transients, the deceleration rate does not vary significantly as the car speed decreases.

Figures 4-22 and 4-23 indicate that the blended braking rate is proportional to the control input level throughout the control range.

Figures 4-24 and 4-25 confirm that the two-car train performance is essentially the same as that for the individual cars. It should be noted (record 1415) that a full-service stop from 70 mph can be performed without exceeding the maximum energy-storage capacity of the ESU.

4.6.4 Deceleration in Service Friction Braking

The service friction-braking performance (with electric braking disabled) for various initial car speeds, car weights, and control input levels is presented in Figures 4-26 through 4-39.

Time histories for friction-braking stops from 80 mph with 98,000- and 130,400-pound car weights are shown in Figures 4-26 and 4-27, respectively. It can be seen in Figure 4-26 that the deceleration rate goes to the required nominal value of -3.0 mphps and remains fairly steady throughout the run. In Figure 4-27 there is some initial overshoot and an increase in deceleration rate as the speed becomes low.

Average, maximum, and minimum values of deceleration rate are plotted as a function of initial car speed in Figures 4-28 and 4-29. The specification requirements for service friction braking are indicated. While the specified limits are exceeded for some runs, the specification is met in most cases.

The time and distance required to stop as a function of initial car speed and control input level are shown in Figures 4-30 through 4-33. For a full-service braking control input and 98,000-pound car weight (Figure 4-30), the stopping time and distance from an initial car speed of 80 mph are 28.5 seconds and 1,660 feet, respectively. This yields an average deceleration rate (0.7335 V^2/S) of 2.83 mphps, which meets the required value of at least 2.7 mphps. The average deceleration rate for a stop from 40 mph is 2.93 mph, which meets the specified value of 2.5 mphps. The average deceleration rate requirements are also met for the 130,400-pound car weight.

Deceleration rate/speed profiles for various control input levels and initial car speeds are shown in Figures 4-34 through 4-37. It can be seen that the deceleration rate increases somewhat when the speed becomes less than about 10 mph; otherwise, the deceleration rate is fairly constant as the speed decreases for most runs.

Figures 4-38 and 4-39 show that the friction-braking rate is proportional to the control input level throughout the control range.

4.6.5 Friction-Brake Duty Cycle

To define the thermal capacity of the friction-brake system and augment the performance characteristics of the friction-brake system presented in Section 4.6.4, various friction-braking duty cycles were conducted with the ACT-1 vehicle. The results of these investigations are presented in Tables 4-III and 4-IV and in Figures 4-40 and 4-41.

Continuous-duty-cycle test results using friction-only braking are shown in Table 4-III and Figure 4-40. The continuous-duty cycle is used to evaluate friction-brake thermal capacity as well as route performance, energy consumption, and propulsion-system characteristics of the ACT-1 vehicle. Test conditions specify operation at AW1 (98,000 pounds) car weight with all stops made at the full-service brake rate. The specification requires that run time for this synthetic transit route (Figure 4-42) be within 39 minutes, with no turnaround allowance between clockwise and counterclockwise route segments. In addition, this route is to be completed including an emergency stop within a braking distance of 1,720 feet from 80 mph immediately following the station stop that has resulted in the highest brake temperature. For successful completion of this test, brake temperature must remain within acceptable limits (950°F) and equipment replacement shall not be required.

In actual performance of the continuous duty cycle with friction-only braking, exceptions to the intended test procedures were made. These were attributed to the use of a single car rather than a two-car train. Specifically, the synthetic transit route was conducted in two counterclockwise segments instead of one clockwise and one counterclockwise segment for a complete round trip. The reason for doing this was to maintain continuous travel in the forward direction without having to turn the car around, end for end, after one segment and affect the temperature gradient. Hence, the route was run starting at station 0 initially (see Figure 4-42) and run in the counterclockwise direction, past station 0 to station A. Then the ACT-1 vehicle was driven a short distance in reverse to Station 0 whereupon a second trip from 0 to A in the counterclockwise direction was conducted. The continuous duty cycle was not repeated to ascertain the effects of performing an emergency stop from 80 mph immediately following the station stop that resulted in the highest brake temperature. This decision was made to avoid exceeding allowable friction-brake temperature limits (950°F) because an emergency stop at this point would have resulted in brake temperatures of approximately 1,130°F.

As shown in Table 4-III, the continuous duty cycle was completed within 37 minutes, two minutes less than that permitted by the specification. A maximum brake-lining temperature of 930°F for disc number 6 was recorded at stations I and H on the second counterclockwise run. It can be noted that for the same control input brake pressures, deceleration rates vary from stop to stop during performance of the route. In some instances this may be attributed to the apparent actuation of the slip-slide system. It is not known for certain whether the actual track conditions or a system malfunction precipitated slip-slide system actuation. Where

TABLE 4–III. CONTINUOUS DUTY CYCLE PERFORMANCE WITH FRICTION BRAKING FOR 98,000-POUND CARWEIGHT

NOTES: 1. 31 INCH WHEELS
2. 600 VOLTS NOMINAL LINE VOLTAGE
3. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-5 RECORD: 5A

	STATION SEGMENT	TIME (MIN)	DISTANCE (MILE)	AVERAGE SPEED (MPH)	MAXIMUM SPEED (MPH)	'P' SIGNAL (MA)	AVERAGE DECEL. (MPHPS)	BRAKE PRESS.[1] FWD (PSI)	BRAKE PRESS.[1] AFT (PSI)	MAX. PAD TEMP[2] (°F)
1st COUNTER CLOCKWISE RUN	O-N	1.77	1.101	37.32	67.93	-1.3	2.959	59.45	57.15	249.5
	N-M	0.88	0.235	16.02	40.73	-1.2	3.049	60.38	57.73	305.7
	M-L	1.20	0.491	24.55	50.15	-1.0	2.826	61.06	58.10	376.8
	L-K	0.92	0.250	16.30	42.84	-0.9	2.861	60.37	58.28	440.6
	K-J	1.72	1.227	42.80	81.40	-0.7	3.042	57.20	53.86	594.7
	J-I	1.92	1.508	47.13	81.22	-0.6	2.964	57.22	54.94	725.5
	I-H	1.17	0.495	25.38	50.64	-0.6	3.478	59.44	56.79	755.6
	H-G	0.92	0.233	15.20	42.07	-0.5	3.268	60.59	(57-15)	775.6
	G-F	0.95	0.272	17.18	41.40	-0.5	3.540	59.30	56.71	760.7
	F-E	1.12	0.512	27.43	50.51	-0.6	3.550	58.82	55.74	743.7
	E-D	1.43	0.754	31.64	60.14	-0.5	3.286	56.48	52.90	765.0
	D-C	1.18	0.488	24.81	50.25	-0.5	3.370	(57-31)	(53-13)	762.0
	C-B	1.70	0.966	34.09	70.56	-0.6	3.081	55.49	53.29	786.3
	B-A	1.33	0.786	35.46	60.37	-0.6	3.026	57.45	53.67	802.8
SUB TOTAL:		18.31	9.318	30.53	—	—	—	—	—	—
2ND COUNTER CLOCKWISE RUN	O-N	1.92	1.106	34.56	66.61	-0.6	2.733	58.53	(57-29)	765.8
	N-M	0.92	0.241	15.72	41.32	-0.5	3.097	59.52	(57-25)	768.0
	M-L	1.18	0.494	25.12	50.35	-0.5	2.906	59.76	56.84	777.3
	L-K	1.02	0.255	15.00	42.27	-0.4	2.420	60.24	(57-11)	791.4
	K-J	1.85	1.309	42.45	81.34	-0.4	2.407	56.11	52.97	883.0
	J-I	2.00	1.516	45.48	81.15	-0.4	2.359	57.08	53.91	930.3
	I-H	1.13	0.430	22.83	50.65	-0.4	2.840	59.04	56.30	930.3
	H-G	0.87	0.220	15.17	42.19	-0.4	2.911	59.25	56.26	918.5
	G-F	0.95	0.276	17.43	39.90	-0.4	2.921	58.75	56.65	892.3
	F-E	1.25	0.509	24.43	50.54	-0.4	2.933	59.28	56.43	871.1
	E-D	1.47	0.762	31.10	60.22	-0.4	2.860	56.61	53.41	869.9
	D-C	1.18	0.467	23.75	50.23	-0.4	3.026	57.39	(53-26)	841.5
	C-B	1.63	0.964	35.48	69.92	-0.5	2.989	(57-21)	53.98	841.5
	B-A	1.28	0.788	36.94	57.58	-0.6	2.910	58.46	54.39	812.6
SUB TOTAL:		18.65	9.337	30.04						
TOTAL		36.96	18.655	30.28						

(1) APPROXIMATE RANGE DURING DUMP SHOWN IN BRACKETS

(2) DISC NO. 6 ; INITIAL TEMP. = 129.7 °F

TABLE 4–IV. FRICTION-BRAKE DUTY CYCLE PERFORMANCE IN EMERGENCY BRAKING FOR 130,400-POUND CAR WEIGHT

NOTES: 1. 31 INCH WHEELS
2. 600 VOLTS, NOMINAL LINE VOLTAGE
3. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOT X-5 RECORD: 1000

STOP SEGMENT	TIME	DISTANCE	AVERAGE SPEED	MAXIMUM SPEED	P SIGNAL	AVERAGE DECEL	BRAKE PRESS FWD	BRAKE PRESS AFT	MAX. PAD TEMP
	(MIN)	(MILE)	(MPH)	(MPH)	(MA)	(MPHPS)	(PSI)	(PSI)	(°F)
1	0.473	0.327	41.48	79.88	-2.505	3.044	83.25	82.96	595.5
2	2.357	2.300	58.55	81.20	-1.679	3.411	82.67	83.71	602.0
3	3.333	3.429	61.73	81.67	-0.955	3.350	81.90	83.19	606.3
4	3.543	3.407	57.70	81.79	-0.715	2.997	82.01	83.10	666.6
5	3.482	3.755	64.70	82.20	-0.547	2.794	82.08	82.69	692.4
TOTAL	13.188	13.218	60.14						

REMARKS
1) INADVERTENT BLENDED BRAKE ENTRY INITIATED FROM 80 MPH ON STOP 3; RECOVERED AND INITIATED EMERGENCY BRAKE ENTRY FROM 70 MPH
2) ON STOP NUMBERS 2, 3 & 4 BRAKE CYLINDER PRESSURE DUMP OCCURRED JUST PRIOR TO THE STOP
3) TEMPERATURE DATA FOR DISC NO 1 SHOWN; PEAK OF 975 °F MEASURED
4) PROFILE: FIVE EMERGENCY STOPS FROM 80 MPH IN 15 MINUTES

brake pressures are maintained and deceleration rates are low, high lining temperature may have resulted in friction-brake fade. Figure 4-40 shows a continuous time history of the brake-lining temperature recorded on disc number 6 for the continuous duty cycle.

Emergency-braking duty cycle test results are shown in Table 4-IV and Figure 4-41. The emergency duty cycle is employed to further evaluate friction-brake-system thermal capacity. Test conditions call for operation at AW3 (130,400-pounds) car weight. The emergency-braking duty cycle consists of five emergency stops from 80 mph in 15 minutes on level tangent tracks. For successful completion of this test, brake temperature must remain within acceptable limits and equipment replacement shall not be required.

As shown in Table 4-IV, the duty cycle was completed in 13.2 minutes, less than the 15 minutes required. The maximum temperature recorded was 692.4°F for disc no. 1 on the final stop. A peak temperature of 975°F was indicated for another disc which was not specifically identifiable due to irregularities in the temperature instrumentation. This may be a spurious result, however. On stops number 2, 3, and 4, there were apparent actuations of the slip-slide system just prior to the stop which did not affect deceleration rates. Some reduction in deceleration rate with increasing brake temperature and stop number is indicated as the deceleration rate decreases from 3.411 mphps on the second stop to 2.794 mphps on the fifth and final stop. The brake pressures on the forward and aft trucks are consistently maintained throughout the emergency-brake duty cycle. Figure 4-41 shows a continuous time history of the brake-lining temperature recorded on disc no. 1 for the continuous duty cycle.

For the continuous duty cycle and emergency duty cycle as performed, the brake temperatures remained within acceptable limits and equipment replacement was not necessary.

4.6.6 <u>Deceleration in Electric Braking</u>

Electric-braking runs (friction brakes disabled) were performed with DOTX-5 at the 98,000-pound weight using full-control inputs only. Time histories for stops from 80 mph and 60 mph are shown in Figures 4-43 and 4-44, respectively. In the run with 80-mph initial car speed, there is some initial overshoot in deceleration rate. Then the ESU reaches its maximum speed at approximately 40 mph as in the blended-braking case. The deceleration rate drops down to a very low value since the friction brakes are disabled. For a 60-mph initial car speed (Figure 4-44), the ESU does not reach maximum speed so the electric braking can be maintained until it fades at just under 4 mph.

The average and maximum excursions in deceleration rate are shown as a function of initial car speed in Figure 4-45. The specification requirements for electric braking are indicated. For initial car speeds above approximately 70 mph, the ESU reaches its maximum speed, resulting in a minimum excursion in deceleration rate that is quite low. For initial car speeds below approximately 70 mph, it can be seen that the specified limits are just slightly exceeded; this is due primarily to the fact that the average deceleration rate is generally 0.15 mphps less than the nominal value of −3.0 mphps. It should be noted that deceleration rate values after the electric-brake fade point (approximately 4 mph) were not considered in determining the minimum excursion values, as permitted by the specification.

The time and distance required to stop as a function of initial car speed are shown in Figure 4-46. For stops from 80 mph, the stopping time and distance are long since the ESU capacity is exceeded. For stops from speeds of 60 mph and below, the stopping time and distance are slightly greater than for blended-braking stops because of the electric braking fade below 4 mph.

Deceleration rate/speed profiles for several initial car speeds are shown in Figure 4-47. Except for some initial overshoot and the 80-mph case when the maximum ESU speed is reached, the deceleration rate does not vary with car speed.

4.6.7 Deceleration in Emergency Braking

The emergency-braking performance for various initial car speeds, car weights, and initiation methods is presented in Figures 4-48 through 4-56.

A time history for an emergency-braking stop from 80 mph with a 98,000-pound car weight is shown in Figure 4-48. After an initial overshoot, the deceleration rate decreases throughout the run until it increases sharply at the end. The brake cylinder pressure remains steady at 70 psig.

The maximum excursions in deceleration rate are plotted as a function of initial car speed for 98,000- and 130,400-pound car weights in Figures 4-49 through 4-51. The emergency braking was initiated by three methods; deadman, pushbutton, and controller. The specification requirement for emergency braking is indicated. The deceleration rate maximum and minimum excursions exceed the specified limits, especially the cases with an initial car speed of 68 mph shown in Figure 4-50.

The time and distance required to stop as a function of initial car speed for 98,000- and 130,400-pound car weights are shown in Figure 4-52. For a 98,000-pound car weight, the emergency-stopping time and distance from 80 mph are approximately 24 seconds and 1,400 feet, respectively. The average deceleration rate ($0.7335\ V^2/S$) is 3.35 mphps, which meets the specification requirement of at least 3.3 mphps. The stopping time and distance are approximately 26 seconds and 1,540 feet, respectively, for a 130,400-pound car weight. This yields an average deceleration rate of 3.05 mphps, which is less than that required. The average deceleration rate for both car weights with a 40-mph initial car speed is 3.35 mphps, which meets the required value of 3.1 mphps.

Deceleration rate/speed profiles for 98,000- and 130,400-pound car weights are shown in Figures 4-53 and 4-54, respectively. It can be seen that there is a substantial decrease in deceleration rate as the car speed decreases, but then there is a sharp increase in deceleration rate below 10 mph.

Figures 4-55 and 4-56 indicate that the emergency-braking performance for a two-car train is essentially the same as for the individual cars.

4.6.8 Control Response

Step changes in control input were performed for the brake-to-drive mode transition at startup and brake-from-coast transition at various car speeds. Full- and partial-control input step changes were performed. The average deadtime and jerk rate for these runs are shown in Tables 4-V and 4-VI, respectively. In Table 4-V the traction motor armature current deadtime is used, except for the friction- and emergency-braking cases where the brake cylinder pressure deadtime is used. DOTX-4 was the instrumented car for the two-car train runs. Figure 4-57 illustrates the jerk-rate variation with control input magnitude and initial car speed for these mode transitions.

Each of the operational mode transitions was performed for both cars and the results are summarized in Tables 4-VII and 4-VIII. Time histories of each of the major types of mode transition are shown for DOTX-5 in Figures 4-58 through 4-65.

The specification requires that the jerk rate in response to rapid control input changes be between 1.5 and 3.0 $mphps^2$. The maximum allowable traction motor armature current or brake cylinder pressure deadtime is 0.5 second for mode transitions requiring contactor changes. For control modulations not requiring a contactor change, the maximum allowable armature current deadtime is 0.2 second and the maximum allowable brake cylinder pressure deadtime is 0.15 second. The applicable specification requirement for each case is indicated in the tables.

In general, there is a substantial amount of scatter in the response deadtime and jerk rate from run to run. However, a number of characteristics can be seen in the results which are summarized as follows.

4.6.8.1 Deadtime Characteristics

a. DOTX-4 met the specification requirements for nearly all the mode transitions in the earlier tests. Subsequent configuration changes appear to have substantially increased the control response deadtime. These configuration changes were required to obtain performance improvements.

b. The deadtime is generally independent of car weight.

c. The deadtime is generally independent of control input magnitude. The only significant exception is small brake-to-drive inputs where the deadtime becomes considerably larger than for large inputs.

d. Although there is a limited number of two-car train runs, those runs indicate that the braking deadtime is somewhat longer than for either car individually.

TABLE 4–V. CONTROL RESPONSE: AVERAGE DEADTIME

NOTES:
1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

MODE TRANSITION	SPEC. REQ. (MPHPS^2)	AVERAGE JERK RATE (MPHPS^2)				
		98,000 LB CAR WEIGHT		130,400 LB CAR WEIGHT		2-CAR TRAIN
		DOTX-4	DOTX-5	DOTX-4	DOTX-5	
BRAKE TO DRIVE AT START-UP	1.5 - 3.0	2.84 (2.10)	4.27 (2.87)	N/A	N/A	2.45
BLENDED BRAKING FROM COAST	1.5 - 3.0	2.16 (2.01)	2.60	1.76 (1.45)	2.43	2.55
ELECTRIC BRAKING FROM COAST	1.5 - 3.0	*	1.73	*	*	*
FRICTION BRAKING FROM COAST	1.5 - 3.0	2.50 (2.30)	3.51 (3.37)	1.84 (1.77)	2.45	3.09
EMERGENCY BRAKING FROM COAST	N/A	11.7	11.9	10.7	9.0	12.1

NUMBERS IN PARENTHESES INCLUDE PARTIAL CONTROL INPUTS

* NOT PERFORMED

TABLE 4–VI. CONTROL RESPONSE: AVERAGE JERK RATE

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

MODE TRANSITION	SPEC. REQ. (SECOND)	AVERAGE DEADTIME (SECOND)				
		98,000 LB CAR WEIGHT		130,400 LB CAR WEIGHT		2-CAR TRAIN
		DOTX-4	DOTX-5	DOTX-4	DOTX-5	
BRAKE TO DRIVE AT START-UP	0.5	0.99 (0.97)	0.79 (0.90)	N/A	N/A	0.79
BLENDED BRAKING FROM COAST	0.2	0.52 (0.55)	0.28	0.48	0.35	0.80
ELECTRIC BRAKING FROM COAST	0.2	*	0.55	*	*	*
FRICTION BRAKING FROM COAST	0.15	0.82 (0.86)	0.48 (0.52)	**	0.46	1.03
EMERGENCY BRAKING FROM COAST	0.15	0.63	0.38	0.65	0.53	**

NUMBERS IN PARENTHESES INCLUDE PARTIAL CONTROL INPUTS

* NOT PERFORMED

** "P" SIGNAL RECORDING INOPERATIVE

TABLE 4–VII. CONTROL RESPONSE: MODE TRANSITION DEADTIME AND JERK RATE OF DOTX-4

NOTES:
1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 98,000 LB CAR WEIGHT
4. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

MODE TRANSITION	DOTX-4 RECORD	DEADTIME (SECONDS)			JERK RATE (MPHPS)	
		SPEC. REQ.	ARMATURE CURRENT	BRAKE PRESSURE	SPEC. REQ.	ACTUAL
BRAKE TO DRIVE AT START-UP	741	0.5(C), 0.15(M)	0.47(C)	0.17(M)	1.5-3.0	2.43
COAST TO DRIVE AT START-UP	742	0.5(C)	0.49(C)	N/A	1.5-3.0	3.99
PARALLEL OFF-LINE TO PARALLEL ON-LINE	743	N/A	0.0	N/A	N/A	0.78
PARALLEL OFF-LINE TO SERIES	744	0.5(C)	1.5(C)	N/A	N/A	2.88
SERIES TO PARALLEL OFF-LINE	744	0.5(C)	0.6(C)	N/A	N/A	2.32
SERIES TO BRAKE	745	0.5(C), 0.2(M)	1.08(C), 0.06(M)	0.16	1.5-3.0	3.86
PARALLEL ON-LINE TO BRAKE	746	0.5(C), 0.2(M)	0.0(C), 0.08(M)	0.08	1.5-3.0	2.02
COAST TO DRIVE ABOVE BASE SPEED	746	0.2(M)	0.13(M)	N/A	1.5-3.0	1.22
SERIES TO BRAKE	747	0.5(C), 0.2(M)	1.05(C), 0.04(M)	0.14	1.5-3.0	3.46
PARALLEL OFF-LINE TO BRAKE	748	0.5(C), 0.2(M)	0.0(C), 0.04(M)	0.14	1.5-3.0	2.17
PARALLEL OFF-LINE TO FRICTION BRAKE	749	0.5(C), 0.2(M)	0.03(M)	0.13(C)	1.5-3.0	2.33
PARALLEL ON-LINE TO FRICTION BRAKE	751	0.5(C), 0.2(M)	0.04(M)	0.14(C)	1.5-3.0	2.07
SERIES TO FRICTION BRAKE	752	0.5(C), 0.2(M)	0.03(M)	0.13(C)	1.5-3.0	2.36
FRICTION BRAKE MODULATION	NOT PERFORMED					

(C) DENOTES THAT MODE CHANGE REQUIREMENT APPLIES, I.E., 0.5 SECOND

(M) DENOTES THAT MODULATION WITHIN A MODE REQUIREMENT APPLIES, I.E., 0.2 SECOND FOR PROPULSION AND 0.15 SECOND FOR FRICTION BRAKES

TABLE 4–VIII. CONTROL RESPONSE: MODE TRANSITION DEADTIME AND JERK RATE OF DOTX-5

NOTES:
1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 98,000 LB CAR WEIGHT
4. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

MODE TRANSITION	DOTX-5 RECORD	DEADTIME (SECONDS)			JERK RATE (MPHPS²)	
		SPEC. REQ.	ARMATURE CURRENT	BRAKE PRESSURE	SPEC. REQ.	ACTUAL
BRAKE TO DRIVE AT START-UP	859	0.5(C), 0.15(M)	1.12 (C)	0.52 (M)	1.5-3.0	3.10
COAST TO DRIVE AT START-UP	860	0.5 (C)	0.78(C)	N/A	1.5-3.0	4.09
PARALLEL OFF-LINE TO PARALLEL ON-LINE	861	N/A	0.0	N/A	N/A	1.72
PARALLEL OFF-LINE TO SERIES	862	0.5 (C)	1.3 (C)	N/A	N/A	2.21
SERIES TO PARALLEL OFF-LINE	862	0.5 (C)	1.0 (C)	N/A	N/A	1.93
SERIES TO BRAKE	863	0.5(C), 0.2(M)	0.35(C), 0.49(M)	0.54	1.5-3.0	2.79
PARALLEL ON-LINE TO BRAKE	864	0.5(C), 0.2(M)	0.0(C), 0.45(M)	0.55	1.5-3.0	1.48
COAST TO DRIVE ABOVE BASE SPEED	864	0.2 (M)	0.35(M)	N/A	1.5-3.0	1.79
SERIES TO BRAKE	865	0.5(C), 0.2 (M)	1.3(C), 0.46(M)	0.56	1.5-3.0	2.29
PARALLEL OFF-LINE TO BRAKE	866	0.5(C), 0.2(M)	0.0(C), 0.31(M)	0.61	1.5-3.0	2.35
PARALLEL OFF-LINE TO FRICTION BRAKE	867	0.5(C), 0.2(M)	0.44(M)	0.54(C)	1.5-3.0	2.59
PARALLEL ON-LINE TO FRICTION BRAKE	869	0.5(C), 0.2(M)	*	1.43 (C)	1.5-3.0	2.77
SERIES TO FRICTION BRAKE	868	0.5(C), 0.2(M)	0.42 (M)	0.52 (C)	1.5-3.0	2.44
FRICTION BRAKE MODULATION	NOT PERFORMED					

* ARMATURE CURRENT WENT TO ZERO JUST PRIOR TO COMMAND INPUT

(C) DENOTES THAT MODE CHANGE REQUIREMENT APPLIES, I.E., 0.5 SECOND

(M) DENOTES THAT MODULATION WITHIN A MODE REQUIREMENT APPLIES, I.E., 0.2 SECOND FOR PROPULSION AND 0.15 SECOND FOR FRICTION BRAKES

e. For blended braking there is an initial application of friction brakes in most cases due to the relatively long electric-braking deadtime. This reduces the vehicle deceleration response time relative to what it would be if the friction brakes were not applied.

f. The series-to-blended braking transition deadtime is large because several contactors have to be opened and closed in the proper sequence to avoid damaging the traction or ESU motors.

4.6.8.2 Jerk Rate Characteristics

a. DOTX-5 jerk rate is generally larger than for DOTX-4.

b. The jerk rate increases with increased control input magnitude.

c. Braking jerk rate is lower at higher initial car speeds, except for blended braking and DOTX-5 friction braking at 130,400-pound car weight, where the jerk rate appears independent of initial car speed.

d. Braking jerk rate is lower for the 130,400-pound car weight than for 98,000 pounds.

e. Two-car train jerk rate is about the same as for the individual cars.

f. DOTX-5 jerk rate for brake-to-drive at startup and friction braking from coast is substantially higher than for the other mode transitions.

In summary, DOTX-4 initially met the specification requirements for deadtime in nearly all cases; subsequent configuration changes appear to have substantially increased the deadtime. The DOTX-5 deadtime is greater than the specified maximum in most cases. For transitions to blended braking, the friction brakes are applied initially so that the vehicle deceleration response time is kept reasonably short. With just a few exceptions, the jerk rate meets the specification requirement of 1.5 to 3.0 mphps^2 for the various control inputs.

4.6.9 Drift Tests

Results of drift tests are presented in Figures 4-66 and 4-67 for the DOTX-4 ACT-1 vehicle at AW1 (98,000 pounds) car weight. Tests were conducted in a forward car direction only on level tangent track. After having attained the desired drift entry speed, the propulsion system was disabled and the car was allowed to coast along the test section.

For performance predictions, the following modified Davis equation is used:

$$F - 116 + (1.3 + 0.045\, V_C)\, W + \alpha \left(\frac{0.2 + 0.3\,(N\text{-}1)}{N}\right) \frac{A}{100} \quad (V_R)^2$$

where

F = train resistance/car weight in pounds

V_R = effective car speed in mph

A = frontal area in square feet

N = number of cars in train

α = 1.0 in open air, 1.7 in tunnels

W = car weight in tons

V_R = V car + V wind, for a headwind

For the ACT-1 at $A = 92.2\ ft^2$, $N = 1$, $\alpha = 1.0$, $W = 49$ tons, and V wind = 0 so that V_R = V car, the above equation reduces to

$$F = 179.7 + 2.21\ V + 0.1844\ V^2.$$

This last equation is portrayed graphically in Figure 4-66. The results of drift tests represented by the data of records 1356 and 1357 are also shown in the same figure for comparison. The test results, which correspond to a car speed range of 55 to 69 mph, indicate that less train resistance exists than that predicted. (Additional drift tests, records 1358 and 1359, corresponding to a 0-to-50-mph speed range, were conducted, but are invalid as the propulsion system was not disabled.)

Train resistance based on the drift tests was established using the equation below:

$$F = \frac{(W + We)}{g} \times \frac{\Delta V}{\Delta t}$$

where W = car weight in pounds

We = 7,760 lb, equivalent mass of rotating inertia

g = 21.937 mphps, gravitational constant

$\frac{\Delta V}{\Delta t}$ = slope of car speed variation with time, mphps.

The slope of car speed versus time for each record was established by a linear fairing through the continuously recorded data. This is illustrated in Figure 4-67, Drift Performance. Although the data contains a high noise content due to an instrumentation problem, the slopes can be accurately defined.

4.6.10 Duty Cycle Performance

Included in this section are the results of continuous duty cycle and short-duration, maximum-capability duty cycle tests.

4.6.10.1 Continuous Duty Cycle

The results of continuous duty cycle tests on the ACT-1 synthetic transit route of DOTX-4 and DOTX-5 vehicles are presented in Tables 4-IX through 4-XI for two-car and single-car train consists. Single-car tests were conducted at AW1 (98,000 pounds) car weight. Two-car train tests were conducted with DOTX-4, the instrumented car, at AW1 and DOTX-5 at AW0 (92,000 pounds) car weights. Table 4-XI presents the special case of continuous duty cycle performance with friction-only braking (this test is also used for the evaluation of friction-brake duty cycle performance presented in Section 4.6.5).

Exceptions to the intended test procedures are as follows: For the continuous duty cycle tests with a two-car train, a maximum speed of 70 mph instead of 80 mph was attained during the clockwise run between stations I and J. In addition, station dwells were 15 seconds or less, instead of 20 seconds. For the continuous duty cycle tests of DOTX-4, single vehicle, the counterclockwise run was performed prior to the clockwise run due to the initial car orientation. Also, to maintain a forward direction of travel, the DOTX-4 car was turned around after completing the counterclockwise run. For the continuous cycle tests of DOTX-5, single vehicle, with friction-only braking, two counterclockwise runs were made to simulate a round trip. The route was run in the counterclockwise direction to maintain the initial orientation of the car and the second run in the same direction was made to avoid having to interrupt testing to turn the car around and thereby affect brake-lining temperature measurements.

As shown in Table 4-IX, continuous duty cycle tests of a two-car train, the total round-trip time not including 3-minute turnaround allowance, is 35.99 minutes; 3 minutes less than the 39-minute specification requirement for schedule time. The corresponding schedule speed with and without the turnaround time allowance is 28.63 and 31.02 mph, respectively. Rms traction motor armature current is 564.9 amperes without turnaround time allowance. This reduces to 542.7 amperes when turnaround time is considered. Energy consumption based on the round trip is 7.12 kw-hr/cm. The average acceleration rate for all starts is 3.183 mphps, which is within specification limits (3.0 ± 0.15 mphps), but many starts (64 percent) exhibit acceleration rates above the specification limit (>3.15 mphps). Whereas the average deceleration rate for all stops is 2.957 mphps, which is within specification limits (3.0 ± 0.2 mphps), several stops (25 percent) show deceleration rates below the specification limit (<2.8 mphps).

As depicted in Table 4-X, continuous duty cycle tests of DOTX-4 vehicle, the total round-trip time not including turnaround allowance is 38.34 minutes, meeting the 39-minute schedule time requirement. The corresponding schedule speed with and without turnaround time allowance considered is 27.25 and 29.38 mph, respectively. Rms traction motor armature current is 543.4 amperes without turnaround time allowance. This reduces to 523.3 amperes when turnaround time is included. Energy consumption for the round trip is 6.93 kw-hr/cm, which is within 2 percent of the two-car train test result. The average acceleration rate for all starts is 3.118 mphps, which is within specification limits (3.0 ± 0.15 mphps); but many starts (46 percent) exceed the maximum average limit (>3.15 mphps) while a few starts are below the minimum average limit (<2.85 mphps). Whereas the average deceleration rate for

TABLE 4–IX. CONTINUOUS DUTY CYCLE PERFORMANCE FOR A TWO-CAR TRAIN

NOTES: 1. 31 INCH WHEELS
2. 600 VOLTS, NOMINAL LINE VOLTAGE
3. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 AND DOTX-5 RECORDS: AB-BA

	STATION SEGMENT	TIME (MIN)	DISTANCE (MILE)	AVERAGE SPEED (MPH)	MAXIMUM SPEED (MPH)	AVERAGE ACCEL. (MPHPS)	AVERAGE DECEL. (MPHPS)	RMS T/M CURRENT ARMATURE (AMPS)	RMS T/M CURRENT FIELD (AMPS)	ENERGY CONSUMPTION (KW-HR)	ENERGY CONSUMPTION (KW-HR/CM)
CLOCKWISE RUN	A-B	1.45	0.734	30.37	59.91	3.302	2.755	538.7	34.5	2.96	4.04
	B-C	1.61	1.009	37.60	70.50	3.296	2.742	551.1	32.9	5.08	5.03
	C-D	1.05	0.482	27.54	51.63	3.458	2.864	534.1	34.0	1.46	3.04
	D-E	1.37	0.743	32.54	59.95	3.246	2.976	580.2	33.7	4.04	5.45
	E-F	1.21	0.511	25.34	51.24	3.239	3.084	542.3	32.6	3.89	7.62
	F-G	0.93	0.261	16.84	40.76	3.227	2.992	504.8	33.9	2.60	9.98
	G-H	0.85	0.236	16.66	41.34	3.231	3.163	530.8	35.2	2.13	9.06
	H-I	1.16	0.503	26.02	51.01	3.212	3.139	558.5	32.8	4.48	8.92
	I-J	2.12	1.465	41.46	70.09	3.212	3.078	612.7	30.9	10.09	6.89
	J-K	1.71	1.244	43.65	80.17	3.072	3.046	599.8	31.5	10.45	8.40
	K-L	0.92	0.287	18.72	41.35	3.011	3.378	520.4	34.4	2.24	7.82
	L-M	1.17	0.487	24.97	51.52	2.993	2.983	569.8	33.4	4.34	8.92
	M-N	0.88	0.247	16.84	40.53	3.314	2.914	518.4	34.6	2.46	9.97
	N-O	1.69	1.117	39.66	76.56	3.332	2.497	547.7	31.9	6.78	6.08
SUB TOTAL		18.12	9.326	30.88	—	—	—	558.3	33.0	63.06	6.76
COUNTER-CLOCKWISE RUN	O-N	1.82	1.150	37.91	72.01	2.912	2.958	635.5	34.1	8.15	7.09
	N-M	0.91	0.251	16.55	42.12	3.045	3.158	526.3	34.8	1.47	5.86
	M-L	1.07	0.422	23.66	51.04	3.054	2.784	578.9	34.8	3.22	7.64
	L-K	0.97	0.318	19.67	42.20	3.344	2.803	490.8	35.3	2.12	6.69
	K-J	1.82	1.317	43.42	82.31	3.366	2.745	550.9	30.8	9.10	6.92
	J-I	1.79	1.357	45.49	81.90	3.251	2.721	566.2	31.0	9.33	6.88
	I-H	1.12	0.491	26.30	51.27	3.266	2.971	523.5	33.6	1.47	2.99
	H-G	0.82	0.236	17.27	41.35	3.179	3.037	536.5	35.6	1.93	8.18
	G-F	0.96	0.277	17.31	42.53	3.188	3.042	514.6	33.8	2.71	9.80
	F-E	1.12	0.497	26.63	50.97	3.206	3.081	510.5	31.6	6.63	13.36
	E-D	1.40	0.757	32.44	60.96	3.134	3.016	580.2	30.9	4.88	6.45
	D-C	1.16	0.455	23.53	50.87	3.080	3.122	558.1	32.0	3.96	8.72
	C-B	1.73	1.133	39.29	71.06	2.949	2.710	646.5	28.7	10.43	9.21
	B-A	1.18	0.618	31.42	60.92	3.006	3.043	640.6	33.7	3.92	6.35
SUB TOTAL		17.87	9.279	31.16	—	—	—	571.4	32.6	69.38	7.48
TOTAL		35.99	18.605	31.02	—	—	—	564.9	32.8	132.45	7.12
TOTAL(1)		38.99	18.605	28.63	—	—	—	542.7	31.5	132.45	7.12

(1) INCLUDES 3 MINUTES TURN-AROUND TIME
(2) INSTRUMENTED CAR: DOTX-4

TABLE 4–X. CONTINUOUS DUTY CYCLE PERFORMANCE FOR 98,000-POUND CAR WEIGHT

NOTES: 1. 31 INCH WHEELS
2. 600 VOLTS, NOMINAL LINE VOLTAGE
3. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 RECORDS: 1220, 1221

	STATION SEGMENT	TIME	DISTANCE	AVERAGE SPEED	MAXIMUM SPEED	AVERAGE ACCEL	AVERAGE DECEL	RMS T/M CURRENT ARMATURE	RMS T/M CURRENT FIELD	ENERGY CONSUMPTION	ENERGY CONSUMPTION
		(MIN)	(MILE)	(MPH)	(MPH)	(MPHPS)	(MPHPS)	(AMPS)	(AMPS)	(KW-HR)	(KW-HR/CM)
COUNTER-CLOCKWISE RUN	O-N	1.77	1.098	37.28	70.66	2.989	2.981	708.4	33.1	9.56	8.71
	N-M	0.93	0.256	16.46	41.88	3.193	3.175	393.9	30.4	1.50	5.86
	M-L	1.30	0.494	22.80	51.00	3.142	2.206[1]	524.7	33.8	3.42	6.92
	L-K	0.97	0.277	17.19	43.63	3.460	2.833	547.0	34.5	1.95	7.04
	K-J	1.87	1.233	39.63	80.01	3.493	2.457[1]	522.6	31.8	8.01	6.50
	J-I	1.97	1.501	45.79	81.05	3.228	2.847	517.1	30.1	8.92	5.94
	I-H	1.20	0.514	25.70	50.45	3.358	3.015	538.1	33.0	1.74	3.39
	H-G	0.93	0.234	15.05	40.48	3.253	3.050	539.0	33.5	2.53	10.80
	G-F	0.97	0.276	17.13	40.68	3.291	3.080	531.2	33.8	2.60	9.45
	F-E	1.23	0.502	24.43	50.44	3.237	3.099	543.1	32.0	3.71	7.40
	E-D	1.50	0.775	31.00	60.94	3.211	2.923	551.9	31.2	5.02	6.47
	D-C	1.23	0.483	23.50	50.96	3.063	3.151	529.4	31.8	4.03	8.35
	C-B	1.67	0.984	35.42	69.17	2.910	3.057	615.3	30.8	9.08	9.23
	B-A	1.50	0.760	30.40	60.45	2.985	2.983	550.8	31.2	4.83	6.35
SUB TOTAL		19.04	9.387	29.58	—	—	—	554.8	32.1	66.90	7.13
CLOCKWISE RUN	A-B	1.47	0.738	30.18	60.21	3.207	2.726	557.7	33.2	3.55	4.81
	B-C	1.67	1.003	36.10	69.65	3.179	2.613	507.5	33.3	4.59	4.58
	C-D	1.23	0.491	23.89	50.95	3.375	2.830	525.9	33.4	1.63	3.32
	D-E	1.50	0.779	31.16	60.09	3.174	2.703	540.4	32.8	4.10	5.27
	E-F	1.23	0.500	24.33	50.61	3.057	2.729	521.8	34.0	3.39	6.79
	F-G	1.00	0.272	16.32	40.71	3.003	2.699	507.9	35.2	2.77	10.21
	G-H	0.93	0.244	15.69	40.53	3.000	2.738	523.9	36.1	2.60	10.65
	H-I	1.23	0.505	24.57	51.29	2.950	2.897	527.7	33.7	4.23	8.39
	I-J	2.10	1.486	42.46	80.00	2.891	2.423[2]	548.6	31.6	11.08	7.45
	J-K	1.87	1.259	40.46	78.80	2.989	2.577	566.7	33.1	9.67	7.68
	K-L	1.00	0.273	16.38	41.64	2.764	3.002	521.5	35.3	2.36	8.67
	L-M	1.27	0.487	23.06	50.42	2.753	2.736	537.1	34.2	4.06	8.34
	M-N	0.97	0.259	16.07	41.84	3.060	2.593	512.5	35.9	2.59	10.03
	N-O	1.83	1.089	35.65	72.44	3.076	2.305[2]	511.6	33.2	6.62	6.08
SUB TOTAL		19.30	9.385	29.18	—	—	—	531.9	33.7	63.24	6.74
	TOTAL	38.34	18.772	29.38	—	—	—	543.4	32.9	130.14	6.93
	TOTAL[3]	41.34	18.772	27.25	—	—	—	523.3	31.7	130.14	6.93

COMMENTS: (1) MASTER CONTROLLER RELEASED
(2) INADEQUATE BCP IN BLEND
(3) INCLUDES 3 MINUTES TURN-AROUND TIME

TABLE 4–XI. CONTINUOUS DUTY CYCLE PERFORMANCE WITH FRICTION BRAKING FOR 98,000-POUND CAR WEIGHT

NOTES: 1. 31 INCH WHEELS
2. 600 VOLTS, NOMINAL LINE VOLTAGE
3. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-S RECORD: 5A

RUN	STATION SEGMENT	TIME (MIN)	DISTANCE (MILE)	AVERAGE SPEED (MPH)	MAXIMUM SPEED (MPH)	AVERAGE ACCEL (MPHPS)	AVERAGE DECEL (MPHPS)	RMS T/M CURRENT ARMATURE (AMPS)	RMS T/M CURRENT FIELD (AMPS)	ENERGY CONSUMPTION (KW-HR)	ENERGY CONSUMPTION (KW-HR/CM)
1st COUNTER-CLOCKWISE RUN	O-N	1.77	1.101	37.32	67.93	2.948	2.959	603.5	18.5	15.01	13.63
	N-M	0.88	0.235	16.02	40.73	2.965	3.049	412.1	24.4	5.08	21.61
	M-L	1.20	0.491	24.55	50.15	2.974	2.826	414.1	21.9	7.42	15.11
	L-K	0.92	0.250	16.30	42.84	3.266	2.861	390.1	22.3	4.99	19.96
	K-J	1.72	1.227	42.80	81.40	3.276	3.042	486.4	17.9	13.43	10.95
	J-I	1.92	1.508	47.13	81.22	3.132	2.964	470.4	17.8	14.94	9.91
	I-H	1.17	0.495	25.38	50.64	3.159	3.478	400.6	23.2	6.72	13.57
	H-G	0.92	0.233	15.20	42.07	3.048	3.268	403.4	22.0	5.01	21.52
	G-F	0.95	0.272	17.18	41.40	3.022	3.540	398.1	24.6	4.43	16.23
	F-E	1.12	0.512	27.43	50.51	3.014	3.550	530.5	19.6	8.47	16.55
	E-D	1.43	0.754	31.64	60.14	2.947	3.286	450.8	20.2	9.74	12.92
	D-C	1.18	0.488	24.81	50.25	2.896	3.370	423.1	22.0	7.78	15.93
	C-B	1.70	0.966	34.09	70.56	2.752	3.081	536.2	19.3	10.47	10.84
	B-A	1.33	0.786	35.46	60.37	2.480	3.026	596.2	14.7	15.77	20.07
SUB TOTAL		18.31	9.318	30.53	—	—	—	484.3	20.2	129.26	13.87
2nd COUNTERCLOCKWISE RUN	O-N	1.92	1.106	34.56	66.61	2.772	2.733				
	N-M	0.92	0.241	15.72	41.32	2.942	3.097	410.3	22.9	4.92	20.41
	M-L	1.18	0.494	25.12	50.35	2.931	2.906	415.1	22.0	8.07	16.33
	L-K	1.02	0.255	15.00	42.27	3.255	2.420	366.8	21.3	5.39	21.13
	K-J	1.85	1.309	42.45	81.34	3.254	2.407	470.5	17.1	13.91	10.62
	J-I	2.00	1.516	45.48	81.15	3.135	2.359	467.4	17.1	15.35	10.13
	I-H	1.13	0.430	22.83	50.65	3.126	2.840	410.0	21.2	6.90	16.04
	H-G	0.87	0.220	15.17	42.19	3.024	2.911	416.2	23.0	4.28	19.44
	G-F	0.95	0.276	17.43	39.90	3.110	2.921	382.8	21.8	5.03	18.24
	F-E	1.25	0.509	24.43	50.54	3.001	2.933	514.2	19.5	9.05	17.79
	E-D	1.47	0.762	31.10	60.22	2.923	2.860	450.3	20.1	10.00	13.13
	D-C	1.18	0.467	23.75	50.23	2.898	3.026	426.9	21.9	7.83	16.77
	C-B	1.63	0.964	35.48	69.92	2.729	2.989	548.1	19.8	13.61	14.12
	B-A	1.28	0.788	36.94	57.58	2.757	2.910	508.9	17.6	9.48	12.03
SUB TOTAL		18.65	9.337	30.04	—	—	—				
TOTAL		36.96	18.655	30.28	—	—	—				

all stops is 2.801 mphps, which is just within specification limits (3.0 ± 0.2 mphps), many stops (46 percent) are below the minimum average limit (<2.8 mphps). In two of these instances the low deceleration rates are attributed to a releasing of the master controller from full-service brake position. In two other cases, the low deceleration rates are due to inadequate blended braking; that is, following the phaseout of electric braking as the ESU speed reached maximum (98 percent), the friction brake system provided less brake cylinder pressure than that for the full-service rate commanded.

As presented in Table 4-XI, continuous duty cycle tests of DOTX-5 vehicle with friction-only braking, the total round-trip time not including the turnaround time allowance is 36.96 minutes; the corresponding schedule speed is 30.28 mph. In addition, rms traction motor armature current is 484.3 amperes for the first counterclockwise run, which is 15 percent less than that for the blended-braking case (Table 4-X). Energy consumption for the first counterclockwise run is 13.87 kw-hr/cm, which is nearly double (+95 percent) that for the blended-braking case. By way of comparison this indicates that the ESU provides a 48.6-percent energy saving with respect to an operational mode of the ACT-1 vehicle in which kinetic energy during deceleration is not recovered while operating on the ACT-1 synthetic transit route. The average acceleration rate for all starts is 2.991 mphps, which meets specification requirements, but a few starts exceed the maximum and minimum specification limits. The average deceleration rate for all stops is 2.986 mphps, which meets specification requirements, but some stops (21 percent) exceed the maximum specification limit and some stops (14 percent) are below the minimum specification limit.

4.6.10.2 Short-Duration, Maximum-Capability Duty Cycle

The results of the short-duration, maximum-capability duty cycle tests are presented in Tables 4-XII and 4-XIII. The test was conducted with the DOTX-5 vehicle at AW1 (98,000 pounds) car weight. This duty cycle consists of 15 minutes minimum of repetitive operation of the following cycle: maximum-power acceleration to maximum speed followed immediately by full-service blended-braking to a stop with a simulated 20-second dwell. Basic performance characteristics are shown in Table 4-XII and maximum equipment temperatures are displayed in Table 4-XIII.

As indicated in Table 4-XII, the total time of repetitive accelerations and decelerations is 15.01 minutes as required. A maximum speed of 80 mph, nominally, was attained on all but the tenth and final acceleration/deceleration cycle, for which a maximum speed of 26.65 mph was attained. This resulted directly from efforts to match the total duty cycle time of 15 minutes exactly. Rms traction motor armature current is 584.5 amperes. Based on rms armature current, the short-duration, maximum-capability duty cycle is about 12 percent more severe than the continuous duty cycle.

4.6.11 Power-Isolation Gap

As part of the ACT-1 test program, the effect on vehicle performance characteristics of traversing a power-isolation gap have been investigated. The power-isolation gap represents a

TABLE 4–XII. SHORT-DURATION, MAXIMUM-CAPABILITY DUTY CYCLE PERFORMANCE FOR 98,000-POUND CAR WEIGHT

NOTES: 1. 31 INCH WHEELS
2. 600 VOLTS, NOMINAL LINE VOLTAGE
3. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-5 RECORD: 878

STOP SEGMENT	TIME	DISTANCE	AVERAGE SPEED	MAXIMUM SPEED	AVERAGE ACCEL	AVERAGE DECEL	RMS T/M CURRENT		ENERGY CONSUMPTION	
							ARMATURE	FIELD		
—	(MIN)	(MILE)	(MPH)	(MPH)	(MPHPS)	(MPHPS)	(AMPS)	(AMPS)	(KW-HR)	(KW-HR/CM)
1	1.67	1.002	36.00	79.63	3.136	2.731	577.7	31.8	7.98	7.96
2	1.65	1.027	37.35	79.58	3.017	2.861	594.8	31.9	7.46	7.26
3	1.62	0.997	36.93	80.10	3.160	2.807	574.9	31.6	6.83	6.85
4	1.65	1.043	37.93	79.94	3.010	2.881	590.5	31.3	7.73	7.41
5	1.60	0.998	37.43	80.44	3.162	2.829	578.0	31.7	7.02	7.03
6	1.65	1.043	37.93	79.97	3.019	2.841	589.3	31.3	7.87	7.55
7	1.60	0.992	37.20	80.48	3.143	2.851	575.5	31.7	7.06	7.12
8	1.67	1.037	37.26	79.77	3.018	2.886	586.0	31.0	7.97	7.69
9	1.60	1.026	38.48	80.26	3.151	2.832	573.0	31.7	6.77	6.60
10	0.30	0.110	22.00	26.65	2.979	2.895	683.8	43.6	0.	0.
TOTAL	15.01	9.275	37.08	—	—	—	584.5	31.8	66.69	7.19

DUTY CYCLE DEFINITION - 15 MINUTES MINIMUM OF REPETITIVE OPERATION OF THE FOLLOWING CYCLE: MAXIMUM ACCELERATION TO MAXIMUM SPEED FOLLOWED IMMEDIATELY BY FULL SERVICE BLENDED BRAKING TO A STOP WITH A SIMULATED 20 SECOND STATION DWELL.

TABLE 4–XIII. SHORT-DURATION, MAXIMUM-CAPABILITY DUTY CYCLE EQUIPMENT TEMPERATURES

NOTES: 1. 31 INCH WHEELS
2. 600 VOLTS, NOMINAL LINE VOLTAGE
3. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-5 RECORD: 878	MAXIMUM TEMPERATURE °F
FWD ESU ACCESS-END BEARING	291
FWD ESU MOTOR-END BEARING	221
FWD ESU OIL FILTER IN	210
AFT ESU ACCESS-END BEARING	281
AFT ESU MOTOR-END BEARING	249
AFT ESU OIL FILTER IN	230
AFT ESU OIL COOLER AIR OUT	162
TRK B-T/M FIELD WINDING	219
TRK B-T/M COMP. WINDING	229
TRK-B-T/M COOLING AIR OUT	170
TRK-A-T/M FIELD WINDING	181
TRK A-T/M COMP WINDING	201

DUTY CYCLE DEFINITION- 15 MINUTES MINIMUM OF REPETITIVE OPERATION OF THE FOLLOWING CYCLE: MAXIMUM ACCELERATION TO MAXIMUM SPEED FOLLOWED IMMEDIATELY BY FULL SERVICE BLENDED BRAKING TO A STOP WITH A SIMULATED 20 SECOND STATION DWELL section of the power distribution system, the third rail, in which there is a substantial reduction or a complete loss of power source or line voltage. Testing was conducted while traversing a power-isolation gap during various accelerative and decelerative conditions at low and high rates. Accelerations were accomplished in parallel offline, parallel online, and series modes. In addition, runs were made with the no-third-rail-enable switch energized and deenergized. The no-third-rail-enable switch, when energized, permits continued operation in parallel offline drive mode using the available energy stored in the flywheel (ESU). When the third rail enable is deenergized, the propulsion control system commands a vehicle stop with a jerk-limited deceleration rate in response to a loss in power source. The results of the power-isolation gap tests are presented in Figures 4-68 through 4-77 for the DOTX-4 ACT-1 vehicle at AW1 (98,000 pounds) car weight.

Figure 4-68 presents power-isolation gap performance during parallel offline drive mode, at a high acceleration rate with no third rail enable. As indicated, the power-isolation gap was entered at a speed of 30 mph and an acceleration rate of 2.8 mphps. The gap was traversed in 3 seconds. Apart from oscillations, armature current and acceleration rate were maintained throughout the power-isolation gap. The oscillations are believed to be caused by the slip-spin system functioning in response to a perceived spin condition.

Power-isolation gap performance during parallel online drive mode, at a low acceleration rate, is shown in Figure 4-69 with no third rail enable and in Figure 4-70 with third rail enable. As shown in each figure, the power-isolation gap was entered at 60-mph car speed and 0.3-mphps acceleration rate. The gap was passed in 1.5 seconds. Both armature current and acceleration rate decreased to zero when power was lost. Then, before the gap was crossed, armature current and acceleration rate increased to initial values prior to entering the gap. With no third rail enable, these values were maintained. With third rail enable, the values of armature current and acceleration rate again decreased to near zero for the remainder of the gap.

Power-isolation gap performance during series drive mode is presented in Figure 4-71, at a low acceleration rate with no third rail enable; 4-72 at a low acceleration rate with third rail enable; 4-73 at a high acceleration rate with no third rail enable; and 4-74 at a high acceleration rate with third rail enable. For these cases the power-isolation gap was entered at 36 to 39-mph car speed and 1.4-mphps acceleration rate, corresponding to the low acceleration rate, and 1.6 to 1.8-mphps acceleration rate, corresponding to the high acceleration rate. The P signals for the high and low acceleration rates were 240 and 180 ma, respectively. Evidently the master controller was not positioned sufficiently close to coast position to achieve a relatively low acceleration rate as intended. Although the power-isolation gap was traversed in 2 to 2.2 seconds, the armature current and acceleration rate remained at zero values for 3.0 to 3.1 seconds and 3.3 to 3.5 seconds, respectively, with no third rail enable, and for 3.9 to 4.0 seconds and 4.0 to 4.2 seconds, respectively, with third rail enable.

Power-isolation gap performance during the brake mode is presented at low brake rate in Figures 4-75 with no third rail enable, and 4-76 with third rail enable. Data is also presented at high brake rate in Figure 4-77 with third rail enable. At the low brake rate conditions, the gap was entered at a 52-mph car speed and −0.8 to −1.5-mphps deceleration rates. At the high brake rate condition, the gap was entered at 40 mph and −2.8-mphps deceleration rate. P-signal values corresponding to the low and high brake rate conditions were 102 to 78 ma, respectively. In all braking cases, the power-isolation gap did not interrupt or affect the braking performance. Also, braking performance was invarient with and with no third rail enable.

It can be seen in Figure 4-77 that after an initial blended-braking entry, armature and field currents decreased to zero and braking was completed with friction-only braking. Furthermore, oscillations in brake pressure and deceleration rate occurred which are believed to be caused by the slip-slide system functioning in response to a perceived slide condition.

4.6.12 Slip-Spin Acceleration

To establish slip-spin acceleration characteristics and evaluate functional capability and slip-spin efficiency, the DOTX-5 ACT-1 vehicle was accelerated from a stop on level, tangent track lubricated with a mixture of detergent and water. Four slip-spin runs were conducted, records 1160-1163, but only the latter two exhibited spins sufficient for analysis. A summary of the test results is presented in Table 4-XIV.

TABLE 4–XIV. SUMMARY OF SLIP-SPIN ACCELERATION PERFORMANCE

Record No.	Speed Regime (mph)	Distance Traveled (ft)	Ideal Distance (ft)	Average Acceleration (mphps)	Avg Peak Acceleration (mphps)	Slip-Spin Efficiency (%)
1162	14.5-26.0	320	131.0	1.07	2.61	40.9
1163	32.8-47.8	680	436.9	1.31	2.03	64.2

As indicated in the table, slip-spin efficiency varied between 41 and 64 percent. Although falling short of the ACT-1 requirement (80 percent), these results reflect the state of the art. Based on subjective evaluations made on the vehicle during these tests and under instances of adverse weather conditions such as wet or icy rails, the slip-spin system functions to maintain car speed or acceleration while not compromising vehicle ride quality.

The following description of the data reduction methodology will also serve as an explanation of some of the items tabulated above. The slip-spin efficiency is defined as:

$$\eta = \frac{(\bar{a}_a) \text{ average car acceleration x 100}}{(\bar{a}_m) \text{ maximum average acceleration for the available adhesion}}$$

To determine the average car acceleration, the following expression is used:

$$(\bar{a}_a) = \frac{V_f^2 - V_I^2}{2 \times S}$$

TABLE 4–XV. SAMPLE CALCULATION OF ACT-1 SLIP-SPIN PERFORMANCE

DOTX-5 Record 1163

Measured values

$$V_f = 47.8 \text{ mph}$$
$$V_i = 32.75 \text{ mph}$$
$$S_2 = 1{,}130 \text{ ft}$$
$$S_1 = 450 \text{ ft}$$
$$S - S_2 - S_1 = 680 \text{ ft}$$

Average car acceleration

$$\bar{A}a = 0.733 \quad \frac{(47.8)^2 - (32.75)^2}{680} = 1.307 \text{ mphps}$$

$$\text{Demonstrated average adhesion} = \frac{1.307}{21.937} = 0.06$$

Calculation for $S_{100\%}$: Minimum theoretical distance traveled from the locus of peak rates.

Time (sec)	$\bar{A}$ Avg (fps^2)	V_1 (fps)	V_2 (fps)	$\bar{V}$ (fps)	S (ft)
1.2-1.3	4.03	48.03	52.07	50.05	50.05
1.3-1.4	3.64	52.07	55.71	53.89	53.89
1.4-1.5	3.01	55.71	58.72	57.21	57.21
1.5-1.6	2.42	58.72	61.14	59.93	59.93
1.6-1.7	2.42	61.14	63.56	62.35	62.35
1.7-1.8	2.61	63.56	66.17	64.87	64.87
1.8-1.9	2.97	66.17	69.14	67.66	67.66
1.9-1.93	3.23	69.14	70.11	69.63	20.91
				$S_{100\%}$ =	436.87 ft

$$\text{Efficiency} = \frac{436.87\ (100)}{680} = 64.2\%$$

$$\bar{A}m = 0.733 \quad \frac{(47.8)^2 - (32.75)^2}{436.87} = 2.034 \text{ mphps}$$

Max average adhesion = 2.034/21.937 = 0.093

For these tests, V_f is selected as the speed beyond which spins do not occur and V_I is selected as the speed just prior to the first spin. S is the distance the car travels in accelerating from V_I initial speed to V_f final speed. Values of speed and distance are obtained from the instrumented ninth wheel which, being unpowered and unable to spin, represents true car speed and distance.

To determine the maximum average acceleration which available adhesion will support, the following expression is used:

$$(\bar{a}_m) = \frac{V_f^2 - V_I^2}{2 \times S_{100\%}} .$$

$S_{100\%}$ represents a theoretical minimum distance to accelerate from V_I initial speed to V_f final speed, based on the peak acceleration rates exhibited during the acceleration run. The $S_{100\%}$ distance is computed by double numerical integration of the acceleration level defined by the locus of peak acceleration rates corresponding to maximum available adhesion.

A sample calculation using this methodology is shown in Table 4-XV. Also, time histories of slip-spin acceleration events are presented in Figures 4-78 and 4-79. These figures show the variation of vehicle acceleration rate, car speed, and traction motor armature currents with slip-spin conditions.

4.6.13 Slip-Slide Deceleration

Slip-slide deceleration characteristics were investigated during full-service blended (records 1164-1166 and 1179), friction only (records 1173-1177), and by deadman actuation, emergency-braking modes (records 1168-1170 and 1172). Tests were conducted employing the DOTX-5 ACT-1 vehicle at AW1 (98,000 pounds) car weight on level tangent track. The test section was lubricated with a mixture of water and detergent to lower the rail-wheel adhesion levels, thereby inducing slides and permitting the slip-slide system to function. A summary of the slip-slide deceleration test results is given in Table 4-XVI.

TABLE 4–XVI. SLIP-SLIDE DECELERATION PERFORMANCE SUMMARY

	Slip-Slide Efficiency	
Deceleration Mode	Specification Requirement (%)	Average of Test Data (%)
Blended Braking	80	75.8
Friction Braking	75 (80% goal)	62.7
Emergency Braking (deadman actuation)	–	59.0

As shown in the table, slip-slide efficiency falls short of specification requirements. However, slip-slide efficiency during blended-braking mode, 75.8 percent, represents the state-of-the-art capability. As was the case with slip-spin acceleration performance, based on subjective evaluations made on the car, the slip-slide system functions to decrease speed and maintain deceleration rate while providing unobjectionable vehicle ride qualities. Further details of slip-slide deceleration performance are presented in Table 4-XVII.

The methodology employed to establish slip-slide efficiency follows. The slip-slide efficiency (η) is defined as:

$$\eta = \frac{(\bar{a}_b) \text{ average car deceleration x 100}}{(\bar{a}_m) \text{ maximum average deceleration for the avail adhesion}} .$$

To determine the average car deceleration, the following expression is used:

$$(\bar{a}_b) = \frac{V_I^2 - V_f^2}{2S} ,$$

where V_I is the car velocity at the instant the first wheel slip occurs and V_f is the car velocity immediately following the cessation of wheel slides (during testing wheel slides did not occur throughout the braking event). S is distance the car traveled from V_I to V_f. Speed and distance were measured using the instrumented ninth wheel.

To determine the maximum average acceleration that available adhesion will support, the following expression is used:

$$(\bar{a}_m) = \frac{V_I^2 - V_f^2}{2S_{100\%}} ,$$

where $S_{100\%}$ represents a theoretical minimum stopping distance from V_I to V_f based on the peak deceleration rates exhibited during the braking event. The $S_{100\%}$ distance is computed by double numerical integration of the deceleration level defined by the locus of peak deceleration rates corresponding to maximum available adhesion.

A sample calculation using this methodology is shown in Table 4-XVIII. In addition, time histories of slip-slide deceleration events are presented in Figures 4-80 through 4-85 for blended, friction, and emergency-braking modes. Included in these figures are acceleration rate, car speed, traction motor currents, brake cylinder pressures, and EP currents.

TABLE 4–XVII. SLIP-SLIDE DECELERATION PERFORMANCE AT AW1 CAR WEIGHT

Level Tangent track
31 INCH wheels
ACT-1 Engineering tests DOT TTC Pueblo Colorado
DOTX 5

RECORD NO (–)	CAR SPEED AT BRAKE ENTRY (MPH)	CAR SPEED AT INITIAL SLIDE (MPH)	CAR SPEED AT SLIDE CORRECTION (MPH)	DISTANCE IN SLIDE (FT)	IDEAL DISTANCE (FT)	AVERAGE DECELERATION (MPHPS)	MAX. AVE. DECELERATION (MPHPS)	DEMONSTRATED AVERAGE ADHESION (μ)	MAXIMUM AVAILABLE AVERAGE ADHESION (μ)	SLIP/SLIDE EFFICIENCY (%)
	BLENDED BRAKING									
1164	80.	73.5	61.4	635	499.7	1.89	2.4	.086	.109	78.9
1165	59.	57.2	37.5	695	476.5	1.97	2.87	.09	.131	68.6
1166	39.	29.5	16.0	250	233.4	1.80	1.93	.082	.088	93.4
1179	22.	18.3	8.0	100	64.5	1.98	3.08	.091	.141	64.5
	DEADMAN-EMERGENCY BRAKING									
1168	80.	76.2	64.8	825	546.3	1.43	2.16	.065	.098	66.2
1169	59.	54.7	42.2	725	423.	1.23	2.10	.056	.096	58.3
1170	39.	31.0	0.	620	313.1	1.14	2.25	.052	.103	50.5
1172	22.	12.5	0.75	64	36.4	1.78	3.14	.081	.143	56.8
	FRICTION BRAKING									
1173	80.	73.5	66.9	555	315.3	1.22	2.15	.056	.098	57.0
1174	60.	53.0	36.5	610	399.0	1.78	2.71	.081	.124	65.4
1175	41.	37.3	20.3	370	224.6	1.94	3.19	.088	.146	60.7
1176	22.	18.4	16.0	25	20.0	2.37	2.96	.108	.135	80.1
1177	26.	22.5	12.5	105	84.5	2.44	3.04	.111	.138	80.5

TABLE 4–XVIII. SAMPLE CALCULATION OF ACT-1 SLIP-SLIDE PERFORMANCE

DOTX-5 Record 1164

S_f	=	1,175 ft	V_f	=	61.4 mph	90.05 ft/sec
S_o	=	540 ft	V_o	=	73.5 mph	107.8 ft/sec
S	=	635 ft				

Average car deceleration

$$\bar{A}a = 0.733 \; \frac{(73.5)^2 - (61.4)^2}{635} = 1.89 \text{ mphps}$$

$$\text{Average demonstrated adhesion, } \mu B = \frac{1.89}{21.93} = 0.086$$

Theoretical distance:

Time (sec)	Deceler (ft/sec^2)	V_1 (ft/sec)	V_2 (ft/sec)	$\bar{V}$ (ft/sec)	S (ft)
0-1	3.49	107.8	104.31	106.06	106.06
1-2	3.30	104.31	101.01	102.66	102.66
2-3	3.34	101.01	97.67	99.34	99.34
3-4	3.59	97.67	94.08	95.88	95.88
4-5.04	3.89	94.08	90.05	92.07	95.75
				$S_{100\%}$ =	499.69 ft

Max average deceleration

$$\bar{A}_M = 0.733 \; \frac{(73.5)^2 - (61.4)^2}{499.69} = 2.4 \text{ mphps}$$

Max average adhesion = 2.4/21.93 = 0.109

$$\text{Slip/slide efficiency} = \frac{1.89 \times 100}{2.4} = 78.9\%$$

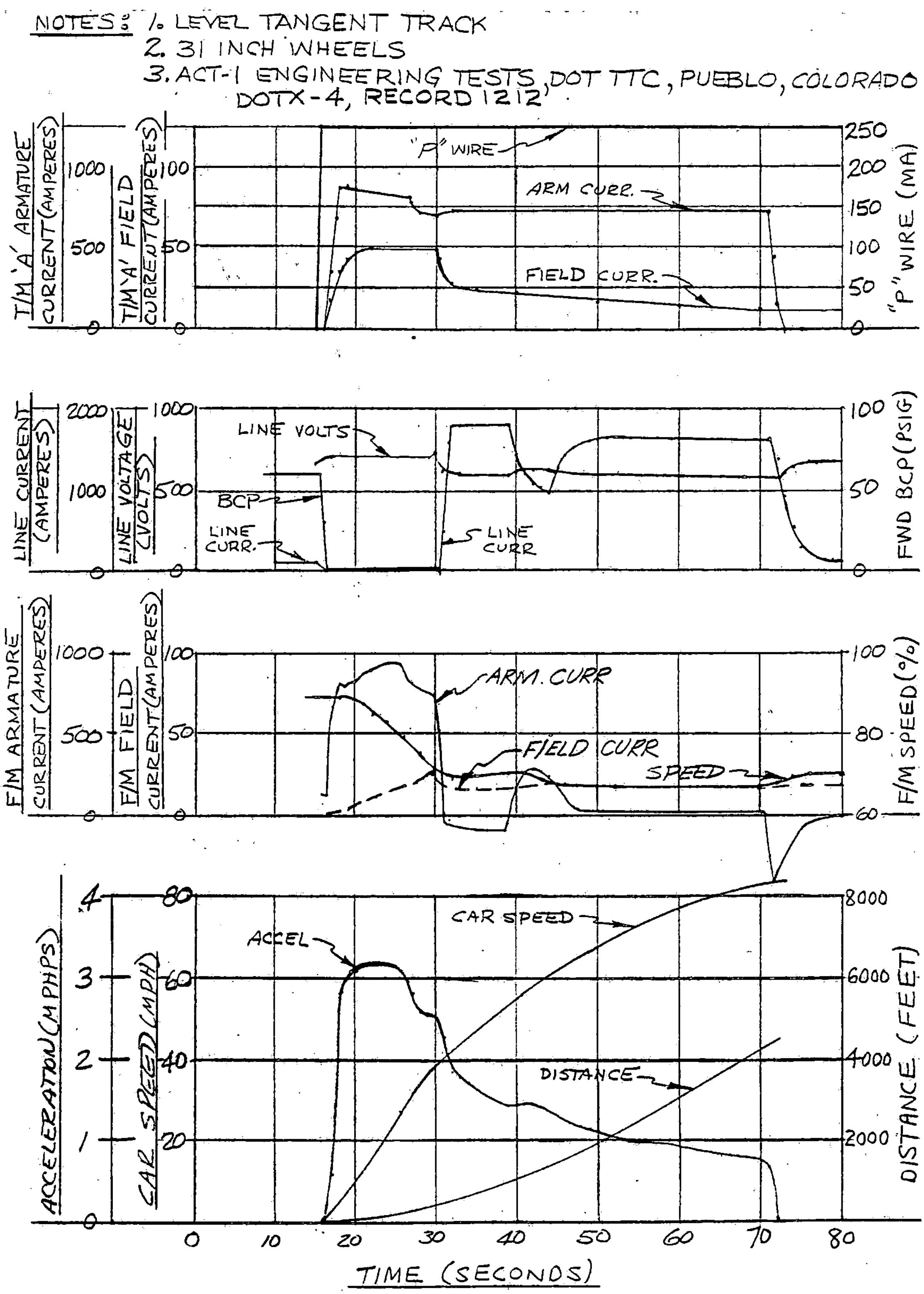


Figure 4–1. Acceleration Time History at 98,000-Lb Car Weight

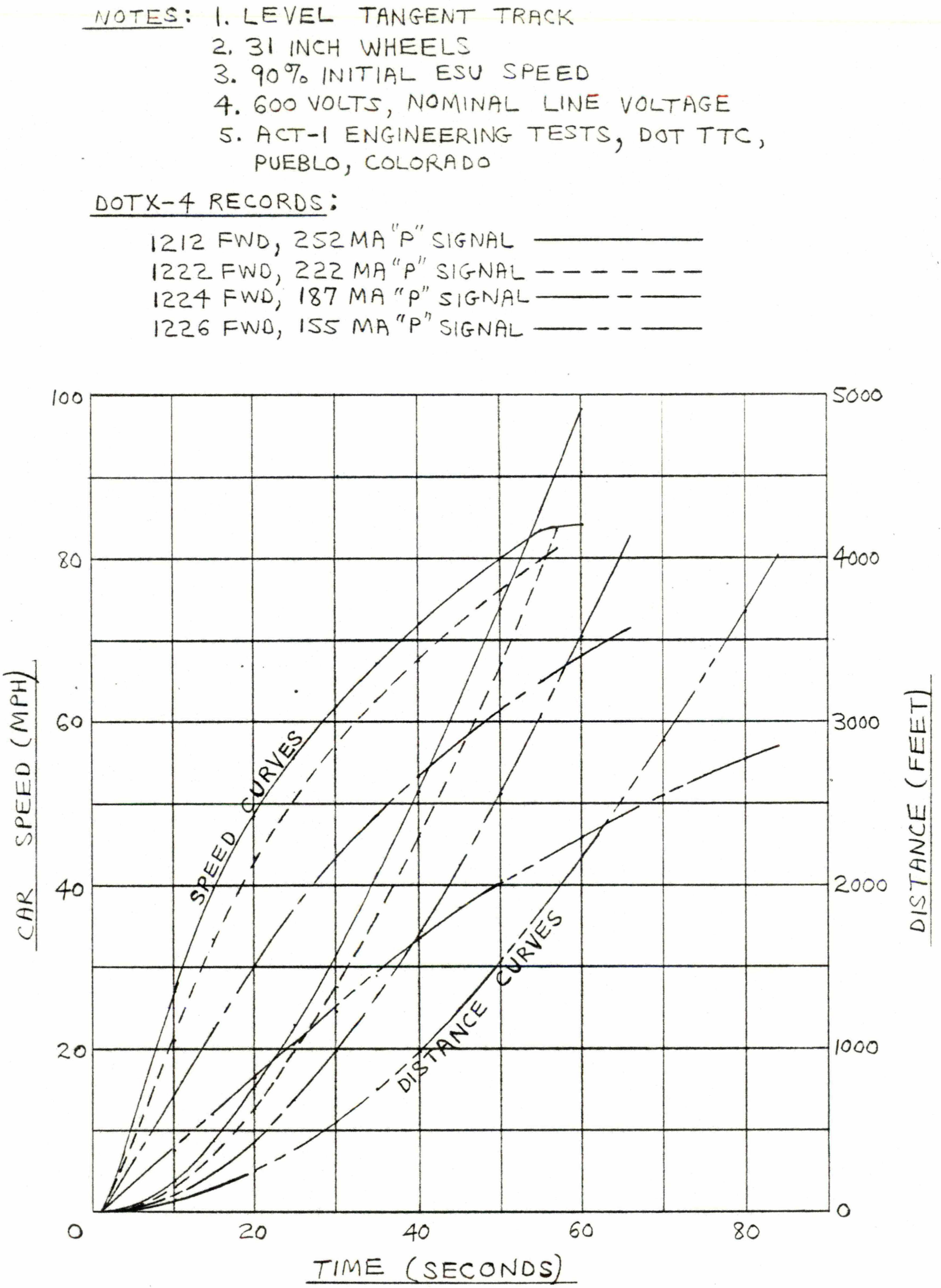


Figure 4–2. Acceleration Performance for Various Control Inputs at 98,000-Lb Car Weight

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 87 % INITIAL ESU SPEED
4. "P" SIGNAL 250 MA
5. ACT-1 ENGINEERING TESTS , DOT TTC,
PUEBLO, COLORADO
DOTX-5

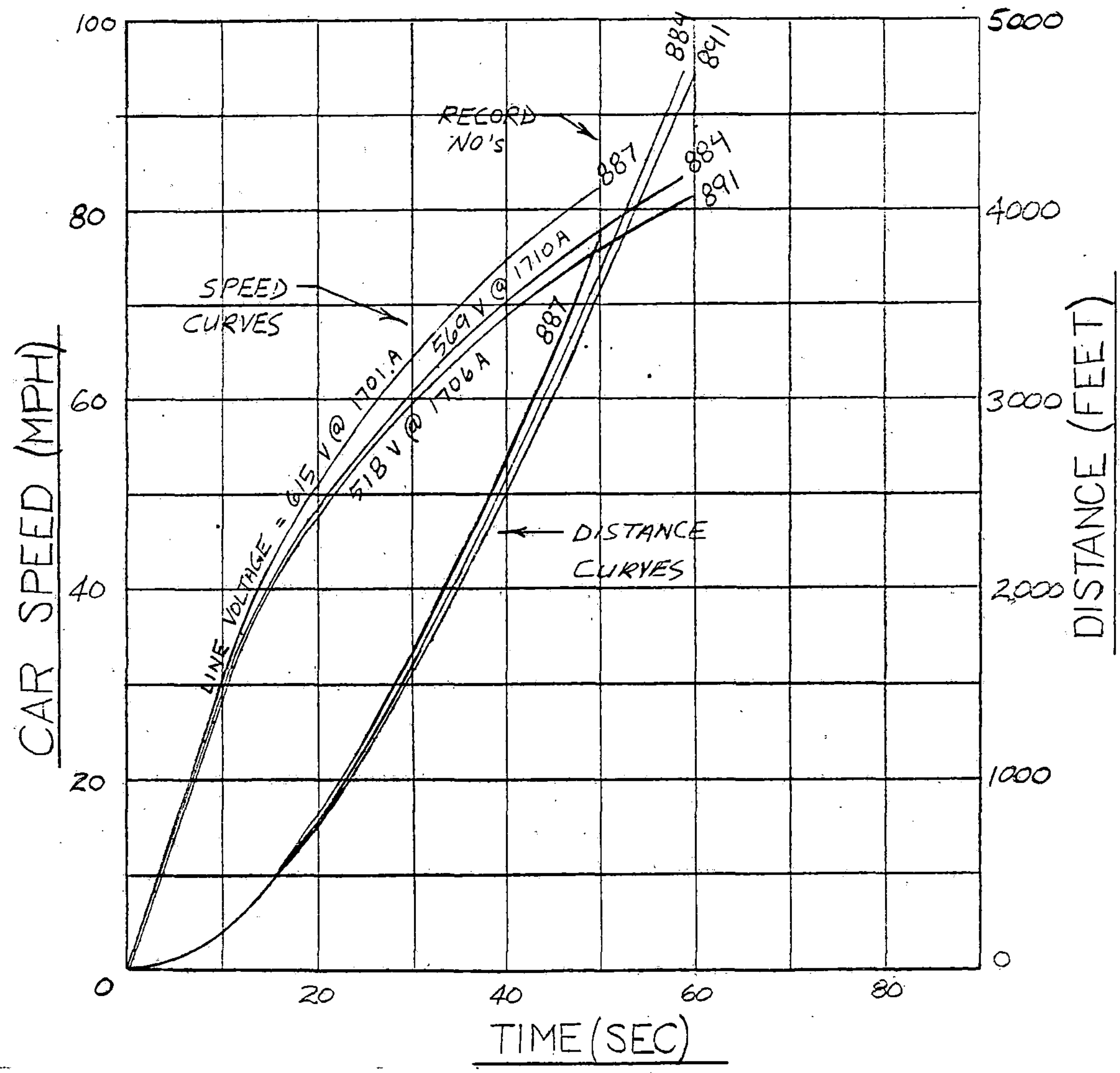


Figure 4—3. Acceleration Performance for Various Line Voltages at 98,000-Lb Car Weight

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 600 VOLTS, NOMINAL LINE VOLTAGE
4. 90% INITIAL ESU SPEED
5. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO
DOTX-4

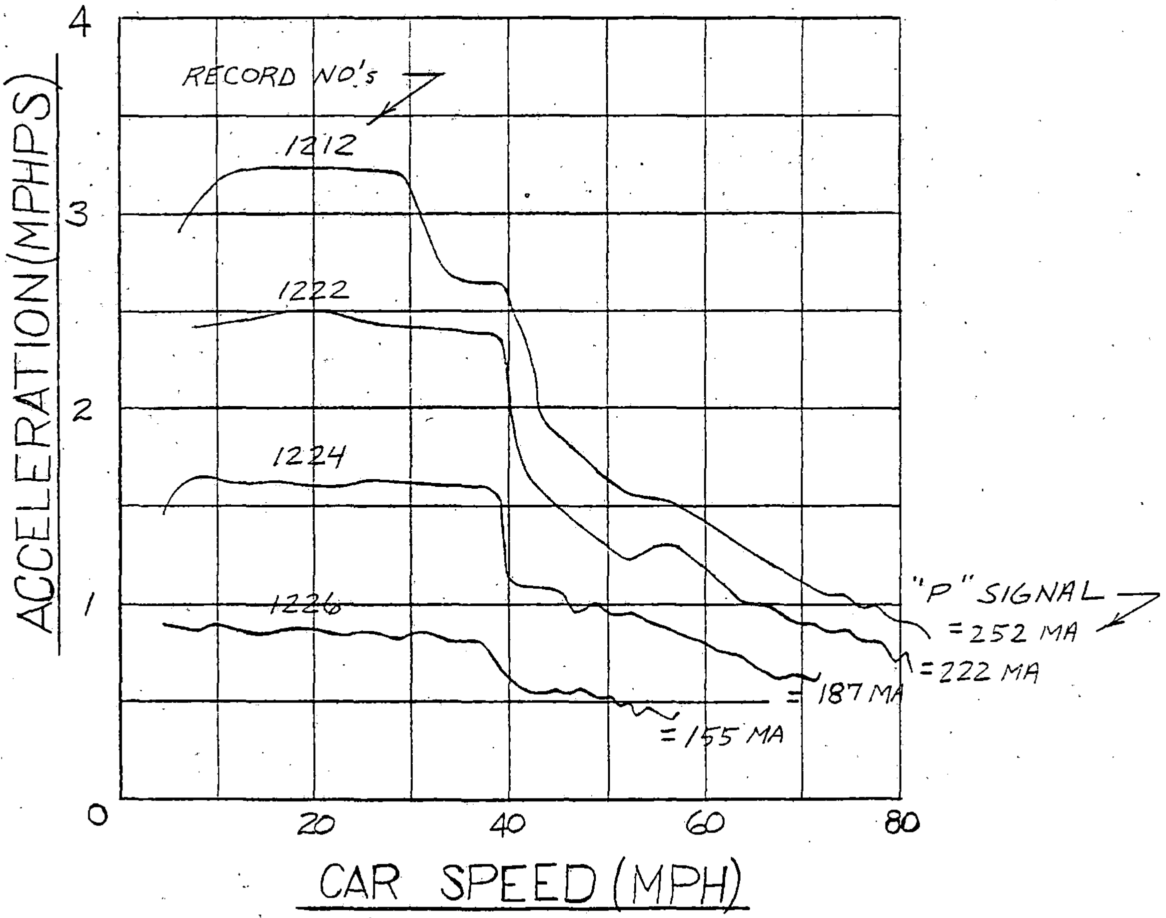


Figure 4—4. Acceleration Rate/Speed Profiles for Various Control Inputs at 98,000-Lb Car Weight

NOTES :

1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 88% INITIAL ESU SPEED
4. 250 MA "P" SIGNAL
5. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOT X-5

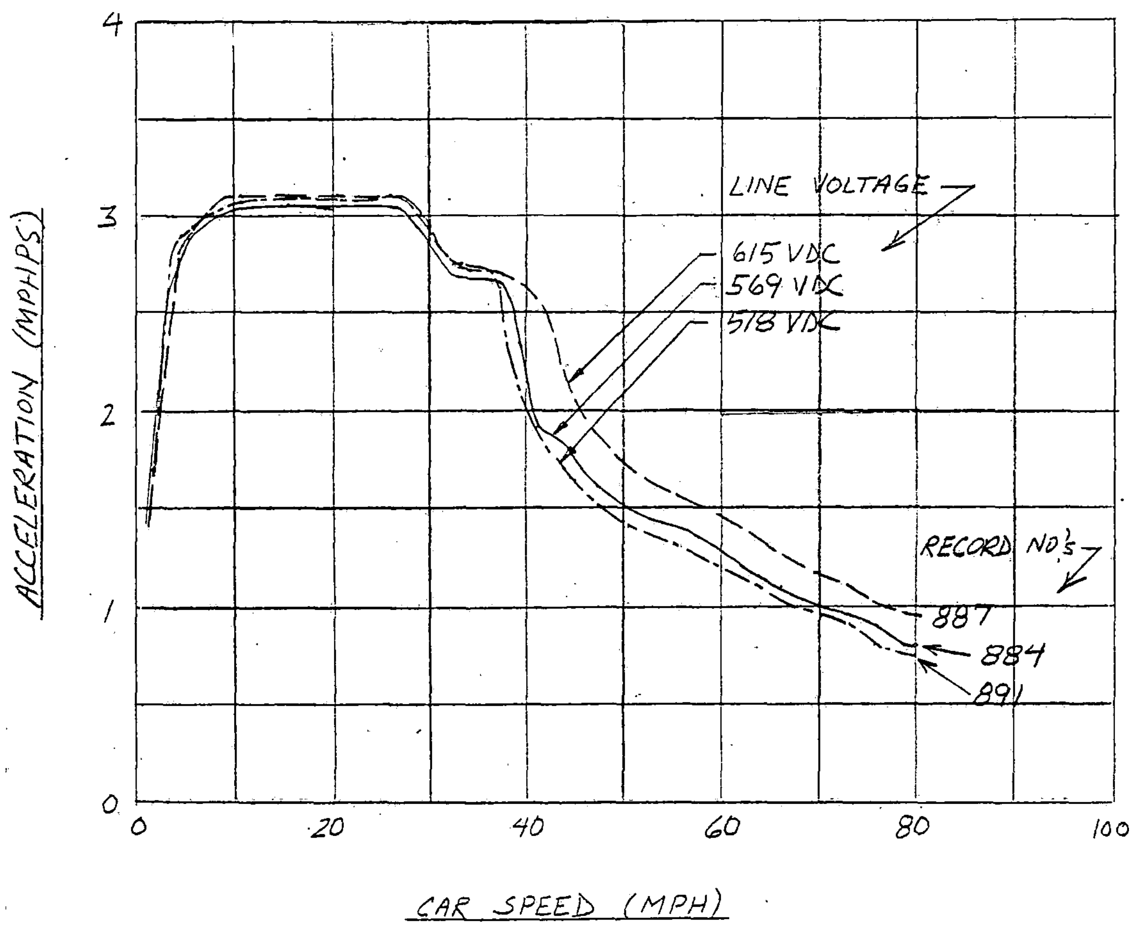


Figure 4–5. Acceleration Rate/Speed Profiles for Various Line Voltages at 98,000-Lb Car Weight

NOTES: 1. LEVEL TANGENT TRACK.
2. 31 INCH WHEELS.
3. 90% INITIAL ESU SPEED.
4. 600 VOLTS, NOMINAL LINE VOLTAGE.
5. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO.

DOTX-4 RECORDS:
- ○-1212 FWD
- □-1216 REV
- ◇-1222 FWD
- △-1223 REV
- ◺-1224 FWD
- D-1225 REV
- ⌂-1336 FWD
- ⬠-1337 FWD
- ◊-1331 REV
- ⌂-1226 FWD
- Δ-1227 REV

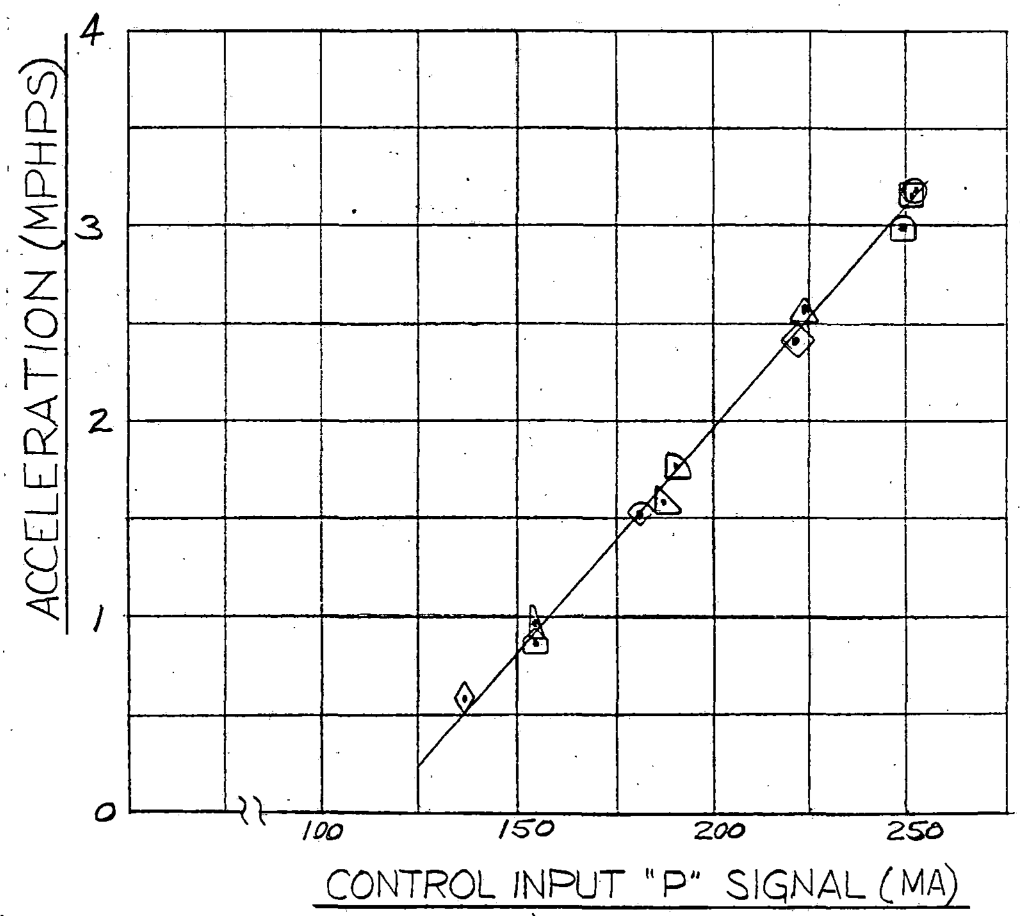


Figure 4–6. Control Linearity in Drive Mode at 98,000-Lb Car Weight

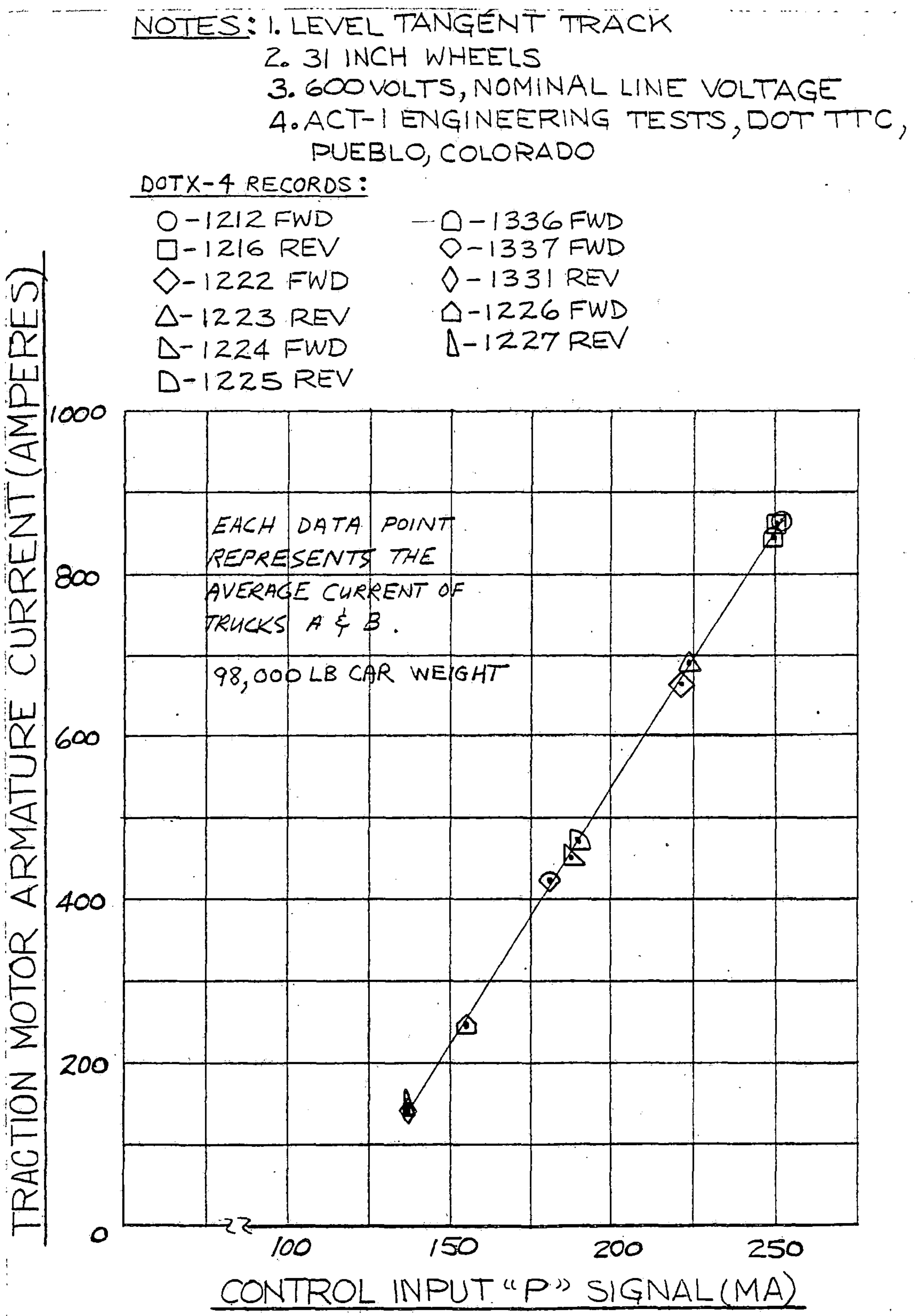


Figure 4—7. Variation of Traction Motor Armature Current With Control Input in Drive Mode

NOTES : 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 600 VOLTS, NOMINAL LINE VOLTAGE
4. 98 % INITIAL ESU SPEED
5. 250 MA "P" SIGNAL
6. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 AND DOTX-5 RECORD: 1406

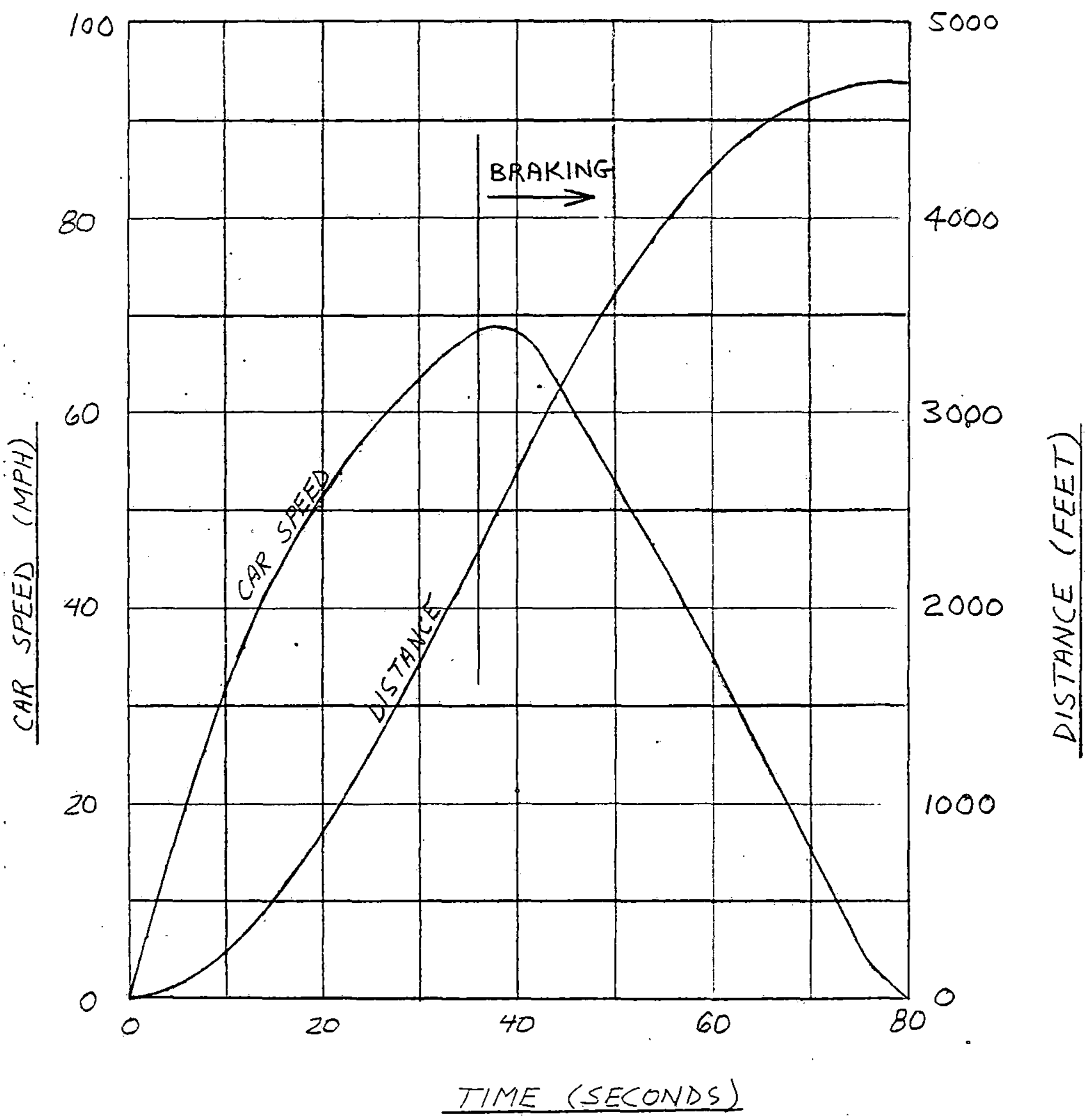


Figure 4–8. Acceleration Performance for a Two-Car Train at 98,000-Lb Car Weight

NOTES :

1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 600 VOLTS, NOMINAL LINE VOLTAGE
4. 98 % INITIAL ESU SPEED
5. 250 MA "P" SIGNAL
6. ACT-1 ENGINEERING TESTS , DOT TTC, PUEBLO , COLORADO

DOTX-4 AND DOTX-5 RECORD: 1406

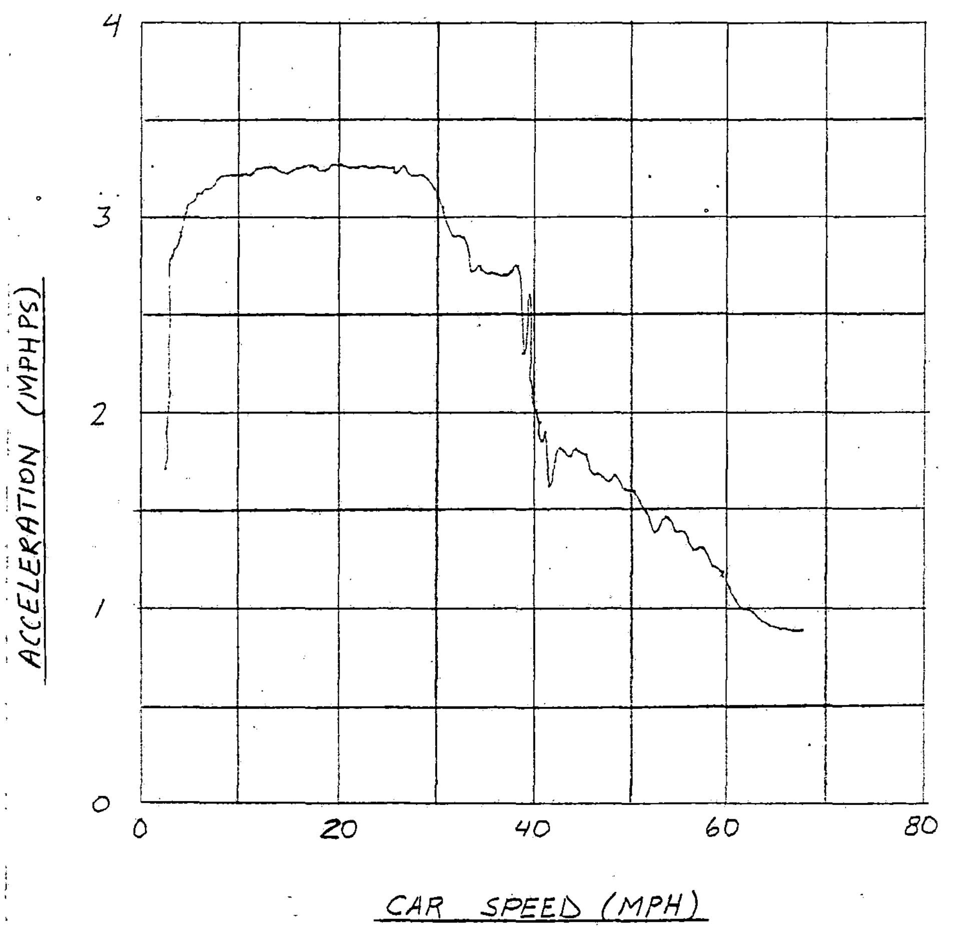


Figure 4–9. Acceleration Rate/Speed Profile for a Two-Car Train at 98,000-Lb Car Weight

NOTES: 1) 31 INCH WHEELS
2) 600 VOLTS, NOMINAL LINE VOLTAGE
3) AUTOMATIC SPEED REGULATION MODE
4) ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO.

DOTX-4 RECORDS:

RECORD	GRADE	RECORD	GRADE
1261	DOWN	1299	DOWN
1262	LEVEL	1300	DOWN
1263	UP	1301	DOWN
1264	DOWN	1302	DOWN
1267	DOWN	1303	LEVEL
1269	UP	1304	LEVEL
1270	DOWN	1305	LEVEL
1271	LEVEL	1306	UP
1272	UP	1307	UP
1273	DOWN	1308	UP
1274	LEVEL		
1275	UP		
1276	DOWN		
1278	UP		

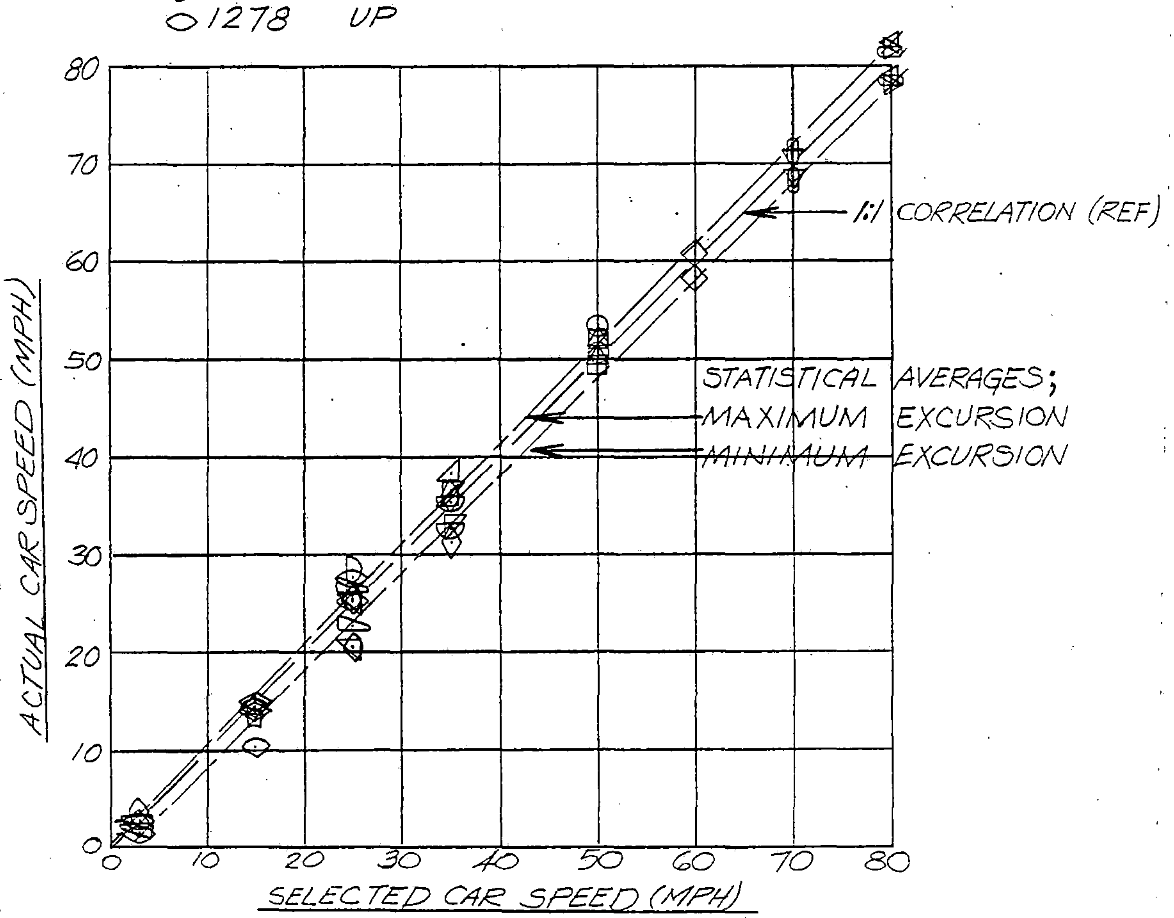


Figure 4–10. Automatic Speed Regulation Operation

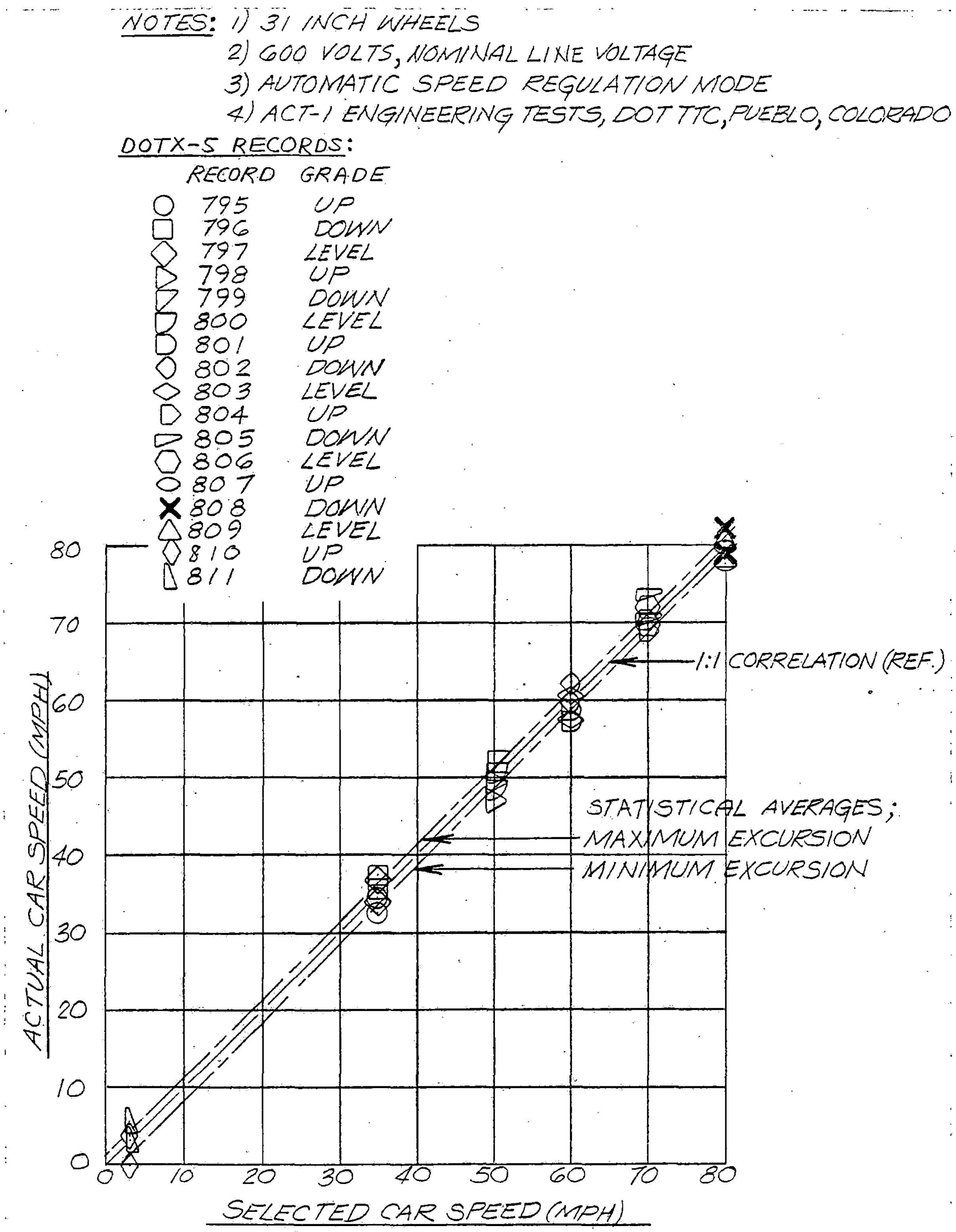


Figure 4—11. Automatic Speed Regulation Operation

NOTES: 1) 31 INCH WHEELS
2) 600 VOLTS, NOMINAL LINE VOLTAGE
3) AUTOMATIC SPEED REGULATION MODE
4) ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 AND DOTX-5 RECORDS:

	RECORD	DIRECTION
○	1435	CW
□	1436	CW
◇	1437	CCW
▷	1438	CCW
▽	1444	CW
▽	1445	CW
D	1446	CW
◇	1447	CCW
◇	1448	CCW

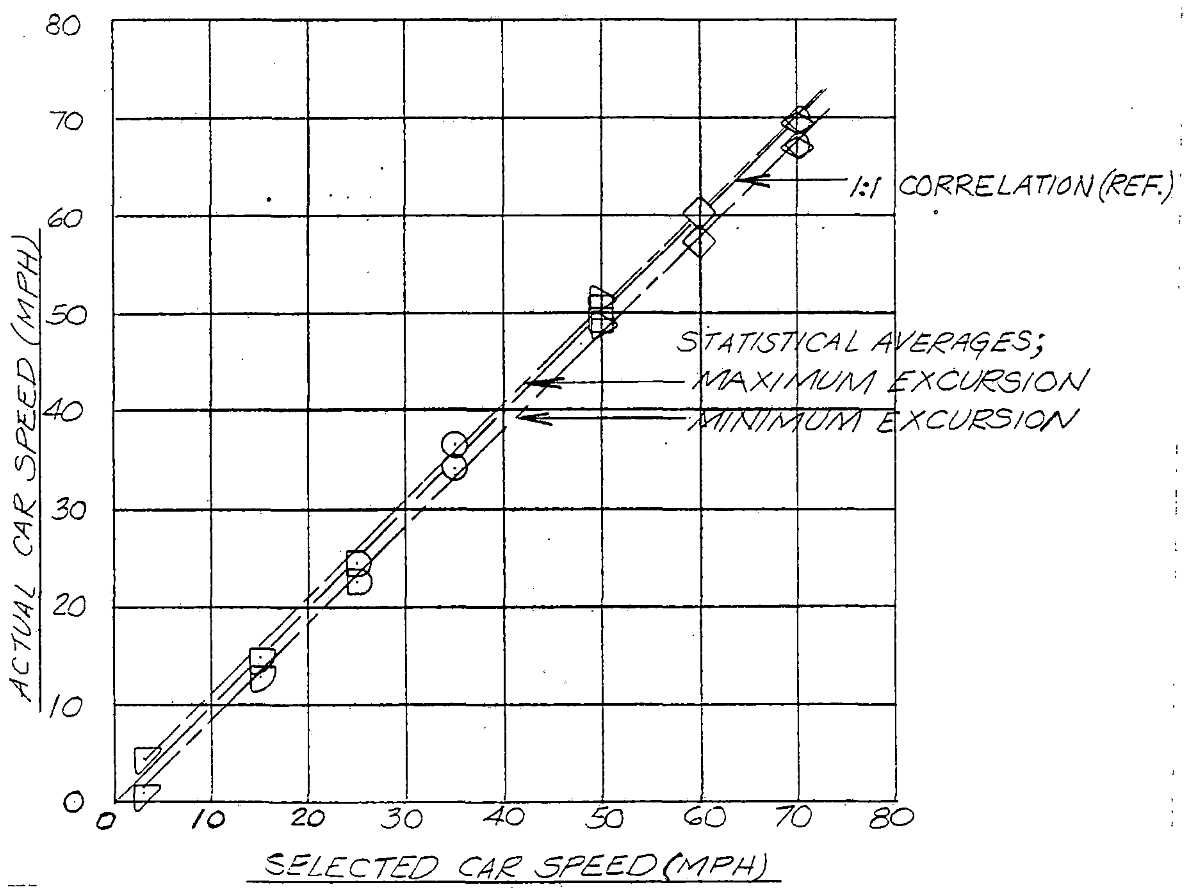


Figure 4–12. Automatic Speed Regulation Operation for a Two-Car Train

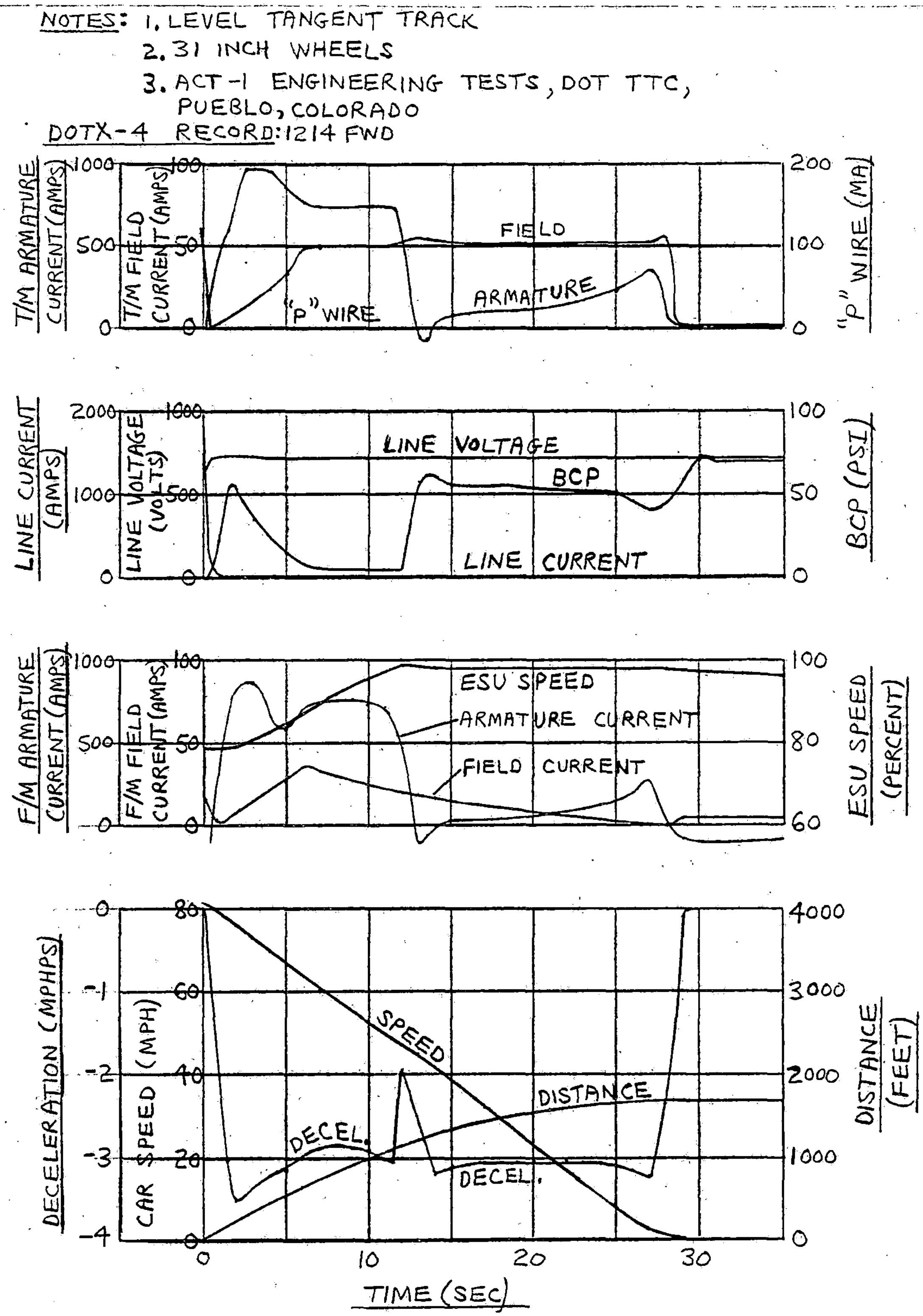


Figure 4–13. Deceleration Time History of Blended Braking at 98,000-Lb Car Weight and 80-mph Initial Car Speed

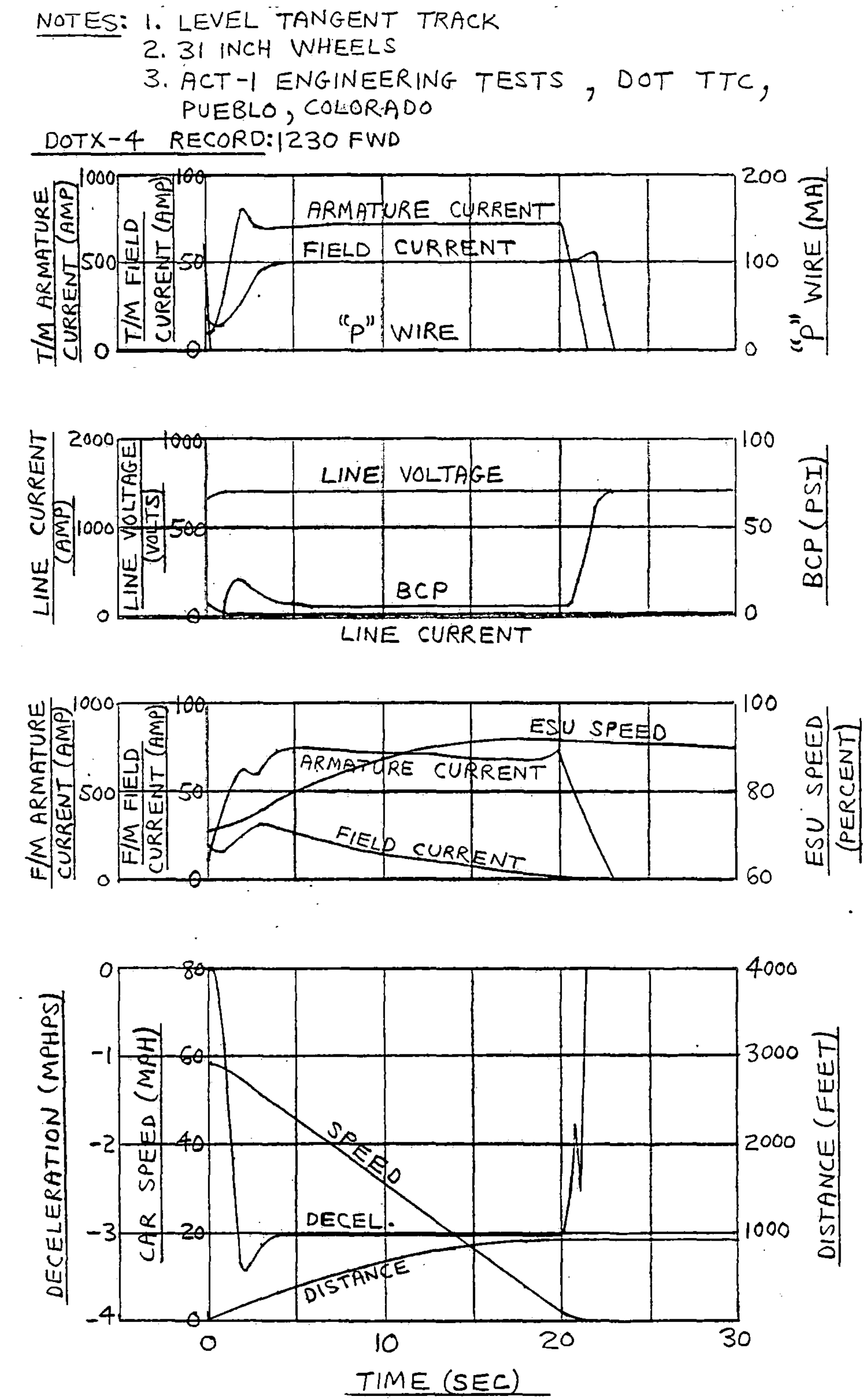


Figure 4–14. Deceleration Time History of Blended Braking at 98,000-Lb Car Weight and 58.3-mph Initial Car Speed

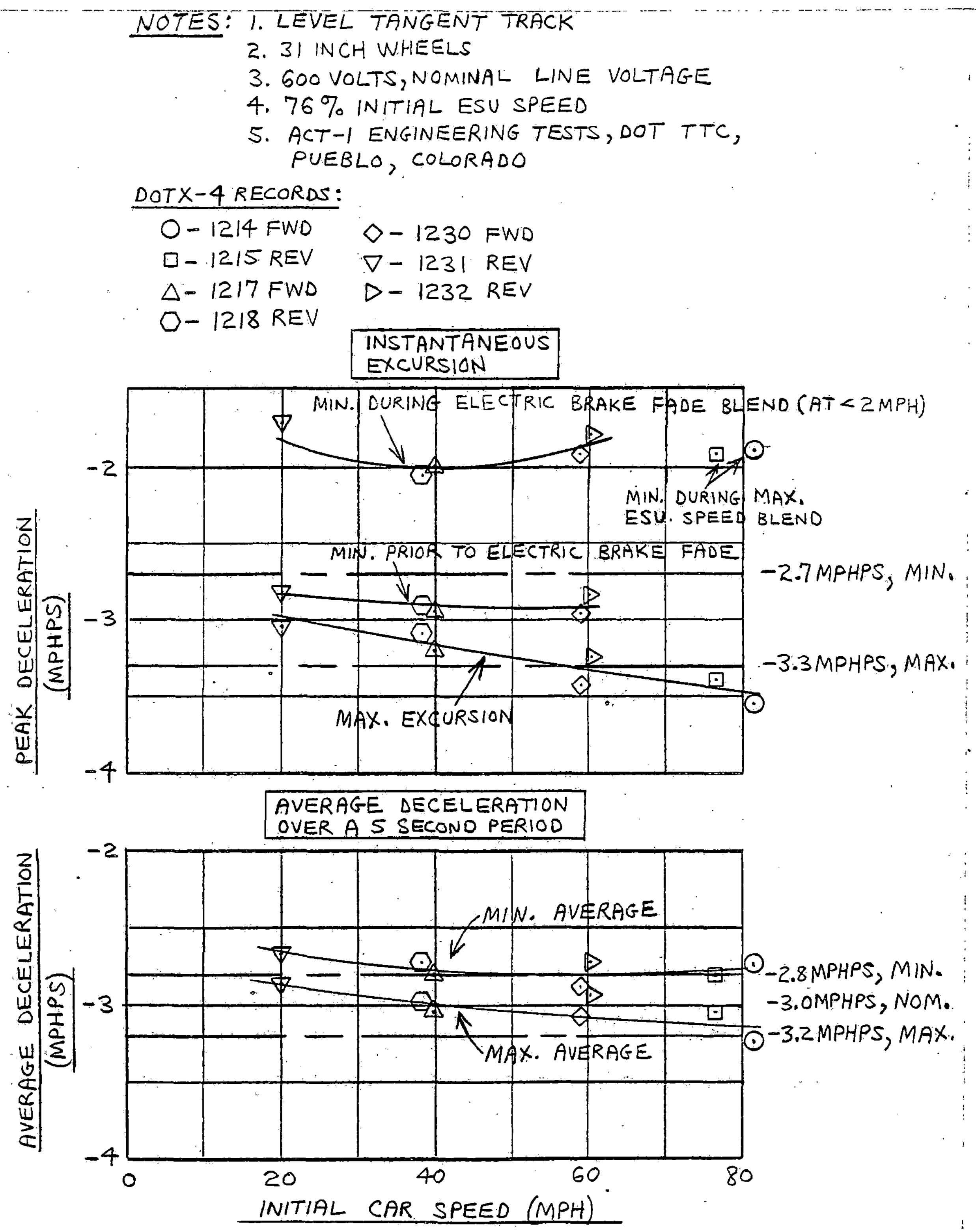


Figure 4–15. Deceleration Rate Characteristics of Blended Braking at 98,000-Lb Car Weight

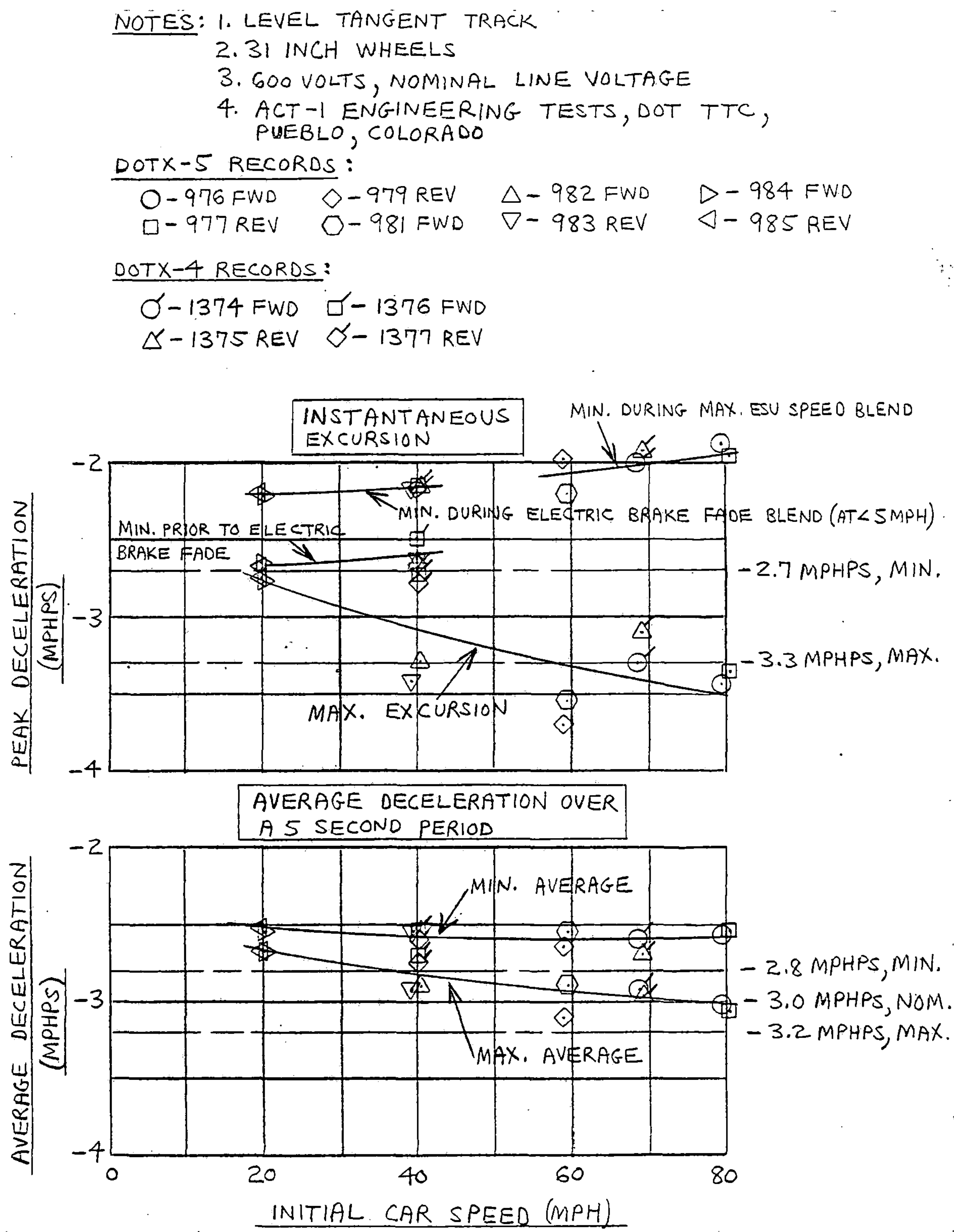


Figure 4–16. Deceleration Rate Characteristics of Blended Braking at 130,400-Lb Car Weight

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 70% INITIAL ESU SPEED
4. 600 VOLTS, NOMINAL LINE VOLTAGE
5. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 RECORDS: 1214 FWD, 1217 FWD, 1230 FWD, 1231 REV, 1233 FWD, 1234 REV, 1339 FWD

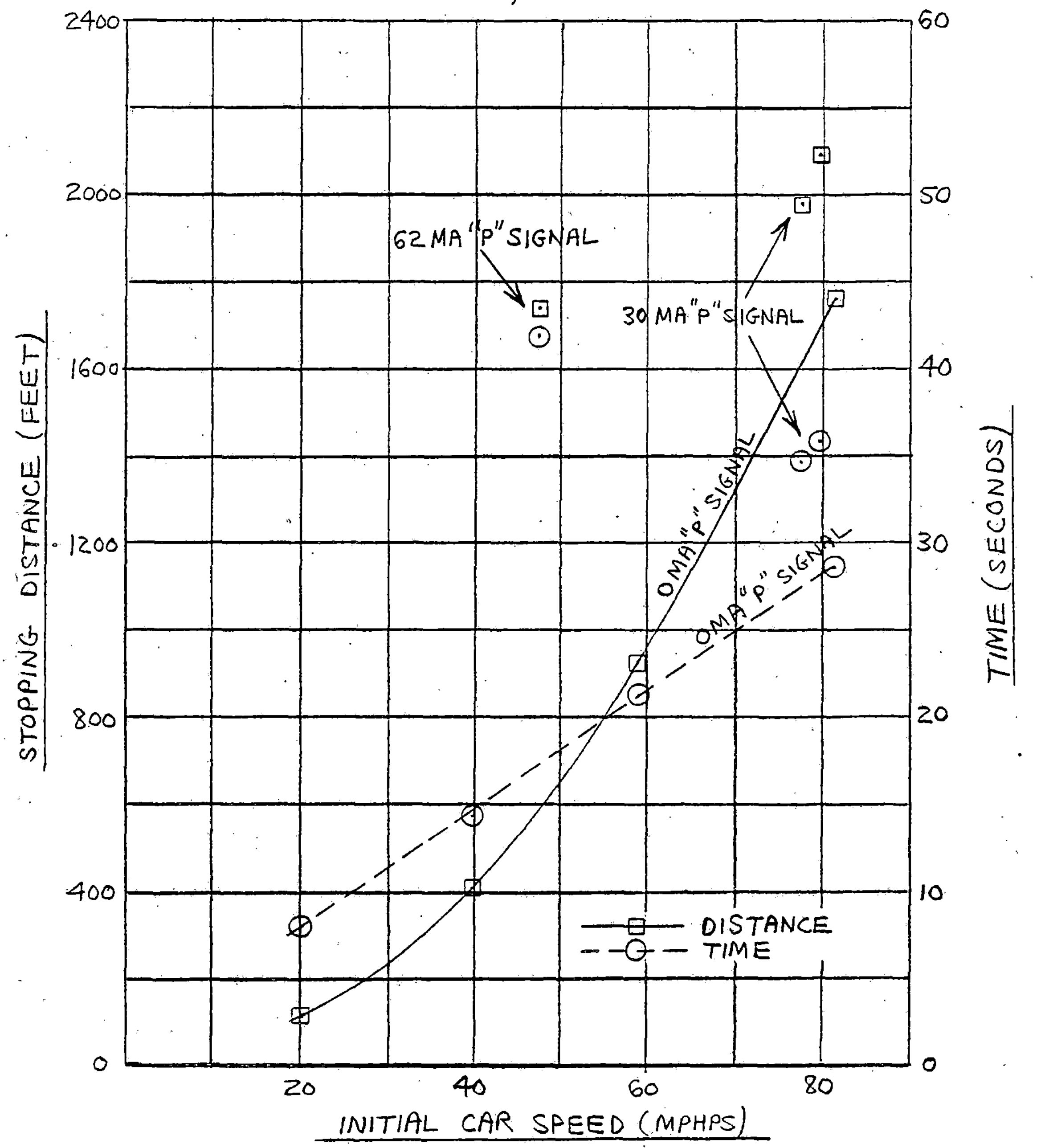


Figure 4–17. Blended Braking Performance for Various Control Inputs at 98,000-Lb Car Weight

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 72% INITIAL ESU SPEED
4. 600 VOLTS, NOMINAL LINE VOLTAGE
5. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 RECORDS:

1214 FWD - 0 MA
1233 FWD - 29.4 MA
1235 FWD - 64.5 MA
1237 FWD - 99.4 MA

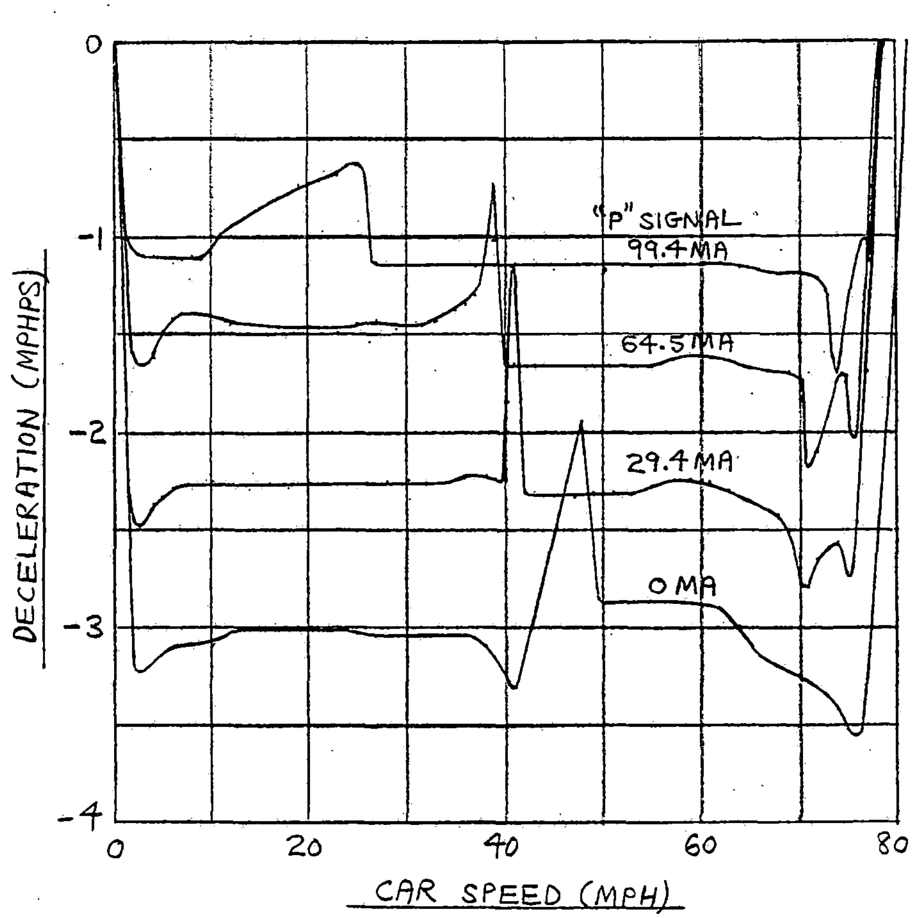


Figure 4–18. Deceleration Rate/Speed Profiles for Various Control Inputs of Blended Braking at 98,000-Lb Car Weight

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 79 % INITIAL ESU SPEED
4. 600 VOLTS, NOMINAL LINE VOLTAGE
5. 0 MA "P" SIGNAL CONTROL INPUT
6. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 RECORDS:

1214 FWD – 81.4 MPH ————————
1217 FWD – 39.2 MPH ——— – ———
1230 FWD – 58.3 MPH – – – – – –
1231 REV – 19.2 MPH ——— – – ———

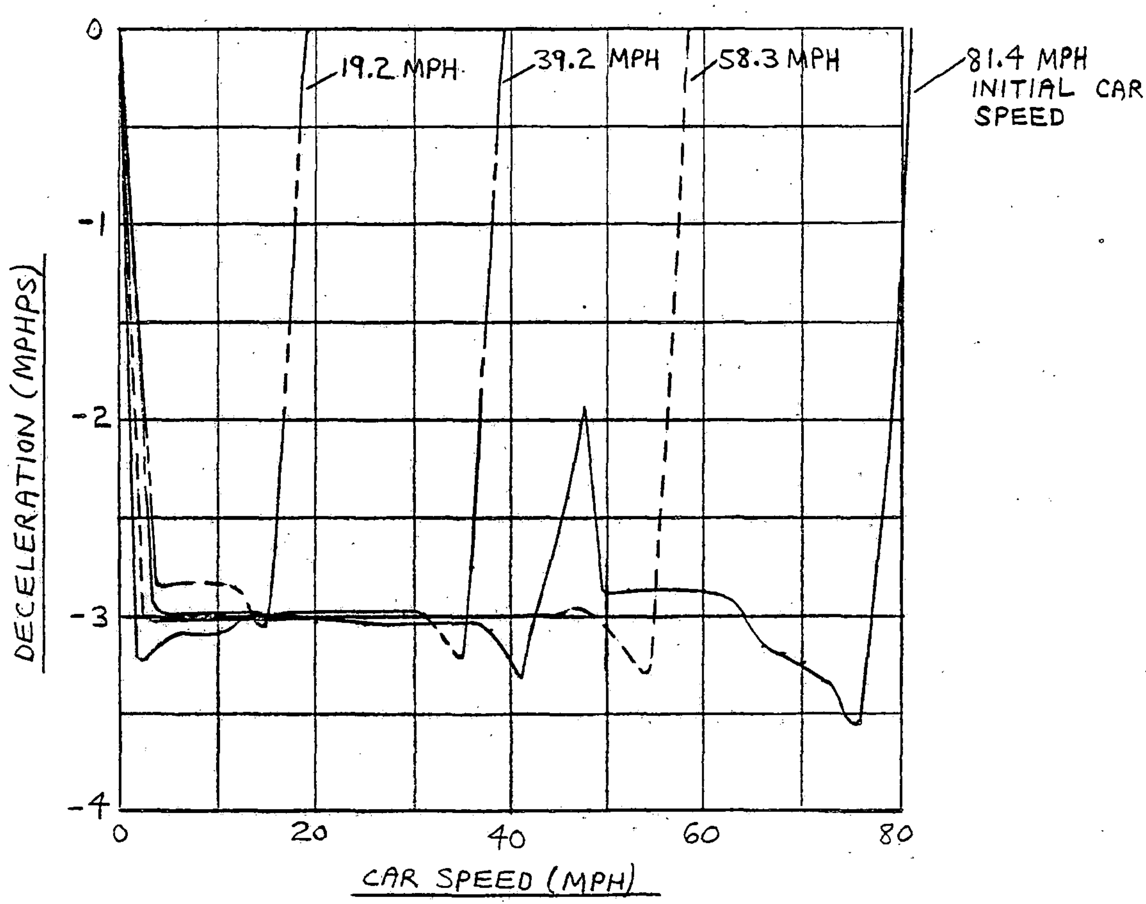


Figure 4–19. Deceleration Rate/Speed Profiles for Various Initial Car Speeds of Blended Braking at 98,000-Lb Car Weight

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 600 VOLTS, NOMINAL LINE VOLTAGE
4. 0 MA "P" SIGNAL CONTROL INPUT
5. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 RECORDS:
1374 FWD - 68.3 MPH ———
1376 FWD - 40.0 MPH – – – –

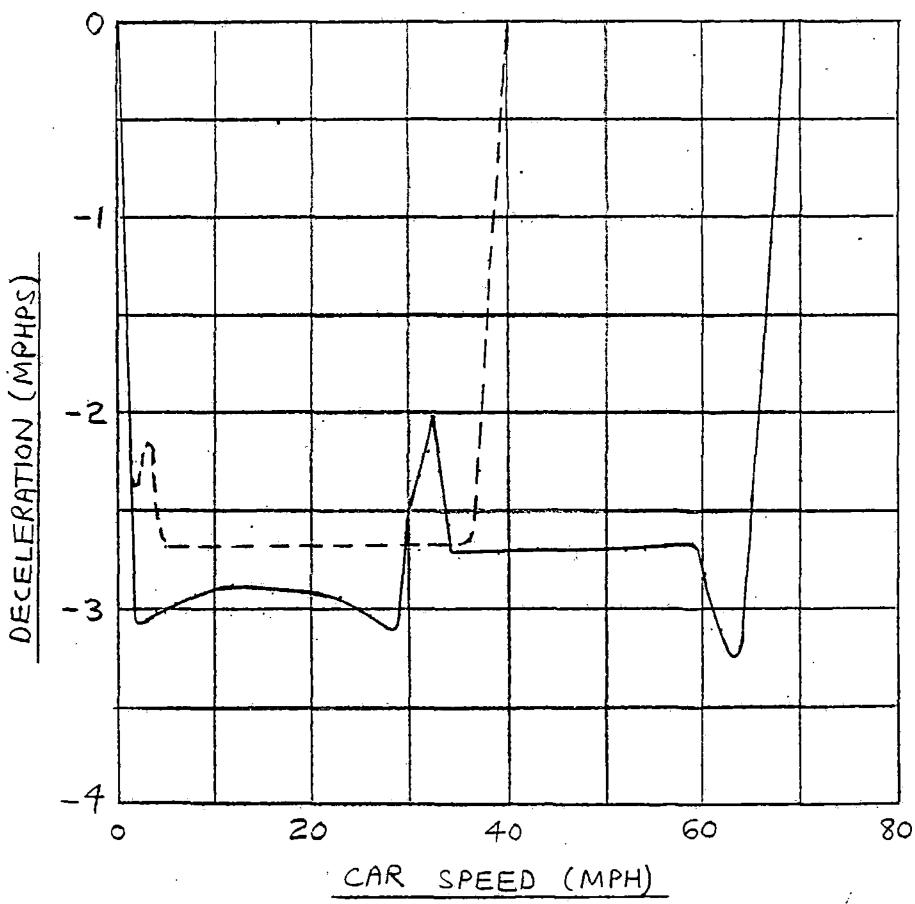


Figure 4—20. Decleration Rate/Speed Profiles for Various Initial Car Speeds of Blended Braking at 130,400-Lb Car Weight

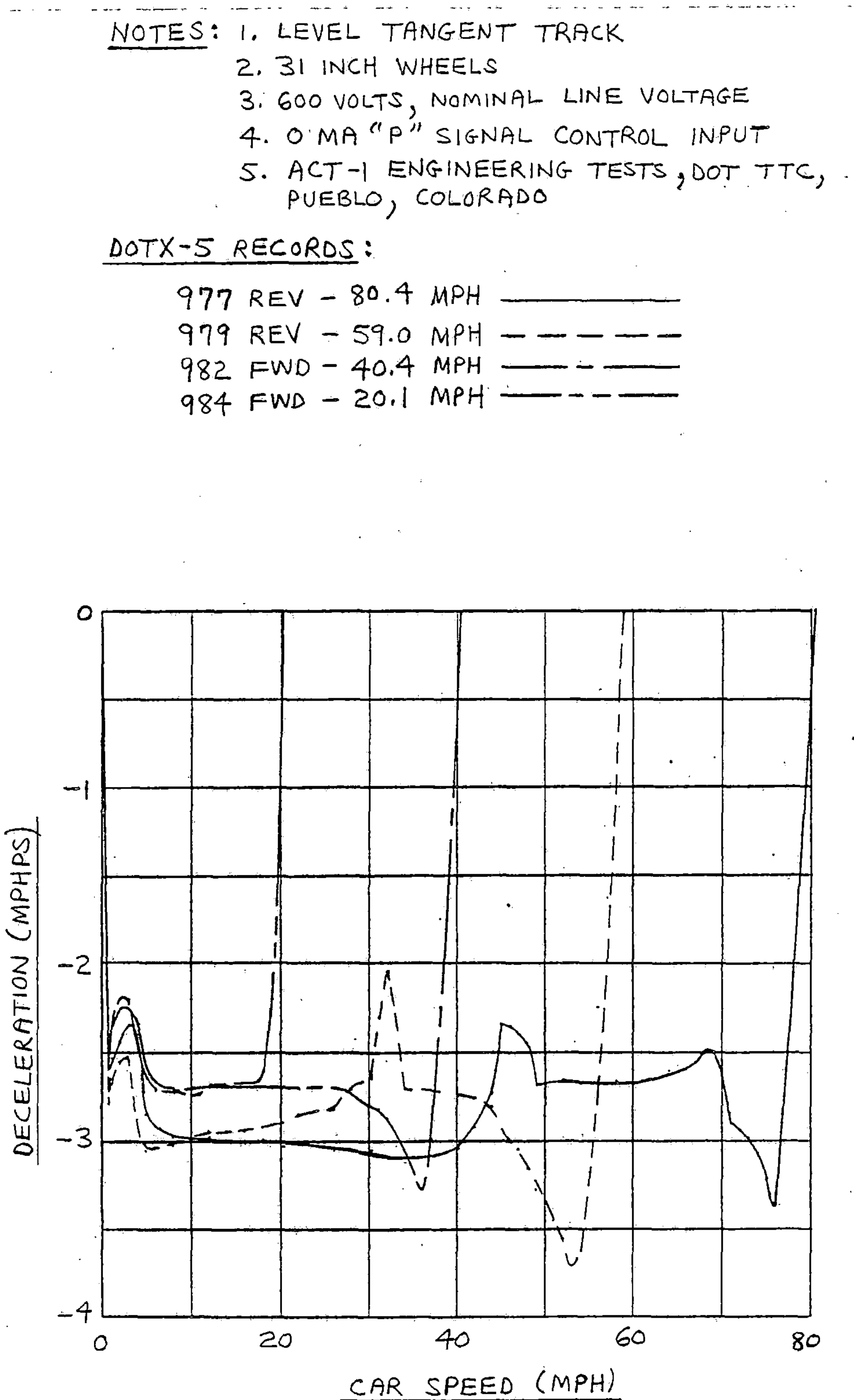


Figure 4–21. Deceleration Rate/Speed Profiles for Various Initial Car Speeds of Blended Braking at 130,400-Lb Car Weight

NOTES : 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 600 VOLTS, NOMINAL LINE VOLTAGE
4. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 RECORDS:

○ – AVERAGE OF 1214 & 1217
□ – AVERAGE OF 1215, 1218, 1231 & 1232
◇ – 1228
△ – 1229
◺ – 1230
D – 1233
⌂ – 1234
◇ – 1235
◊ – 1236
⌂ – 1237
▵ – 1238
⬡ – 1338
0 – 1339

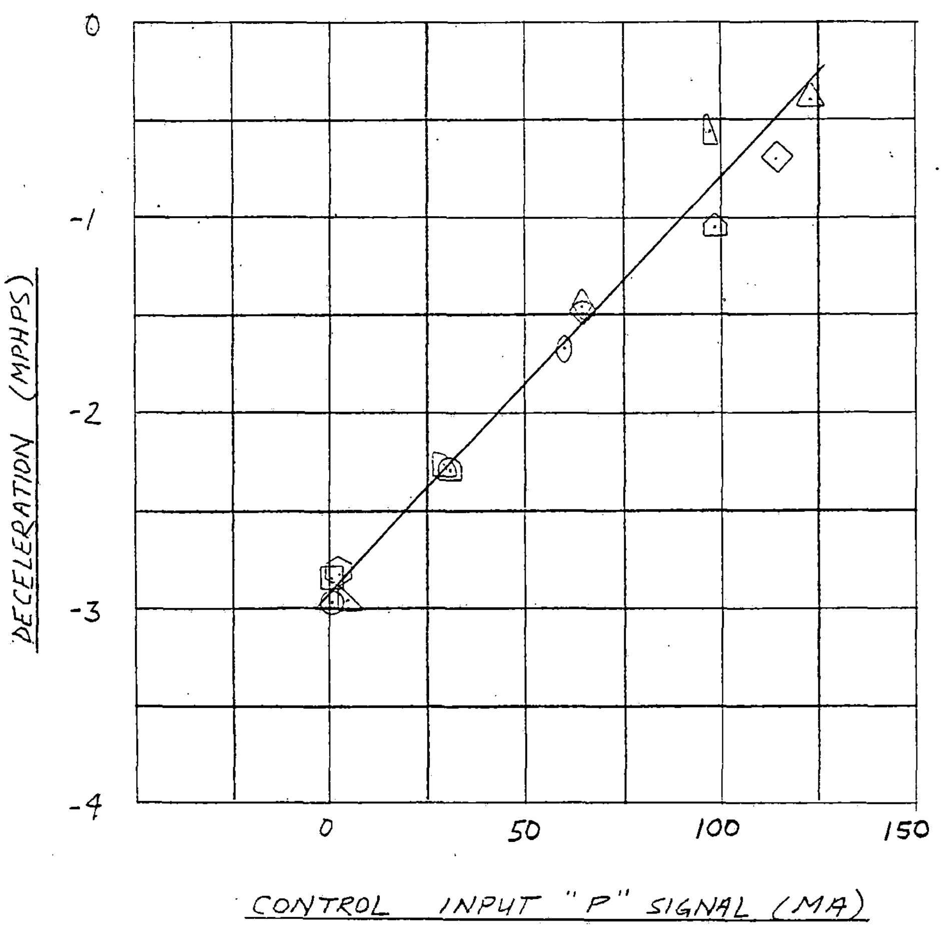


Figure 4—22. Control Linearity of Blended-Braking Mode

NOTES :
1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 600 VOLTS, NOMINAL LINE VOLTAGE
4. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 RECORDS:

○ – AVERAGE OF 1214 & 1217
□ – AVERAGE OF 1215, 1218, 1231 & 1232
◇ – 1228
△ – 1229
– 1230
– 1233
– 1234
– 1235
– 1236
– 1237
– 1238
⬡ – 1338
0 – 1339

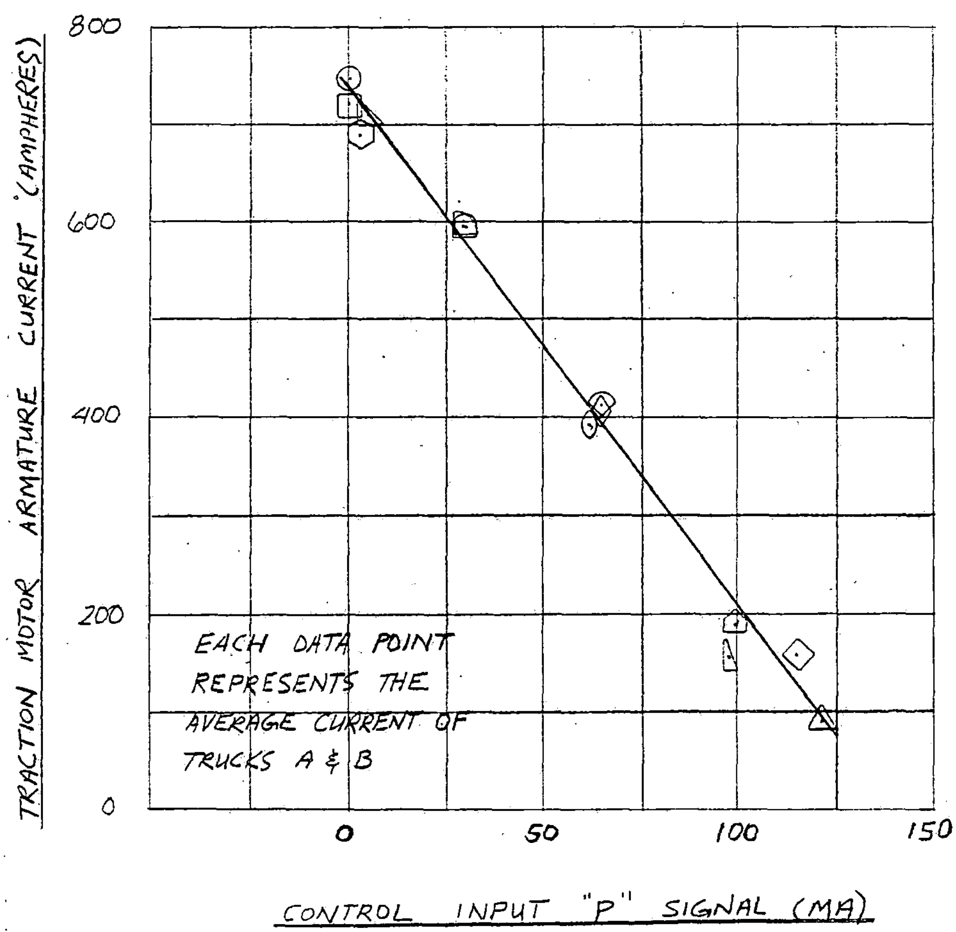


Figure 4–23. Variation of Traction Motor Armature Current With Control Input in Blended-Braking Mode

NOTES:
1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 600 VOLTS, NOMINAL LINE VOLTAGE
4. 0 MA "P" SIGNAL
5. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 AND DOTX-5 RECORDS:

○ – 1408
□ – 1409
◇ – 1410
△ – 1415

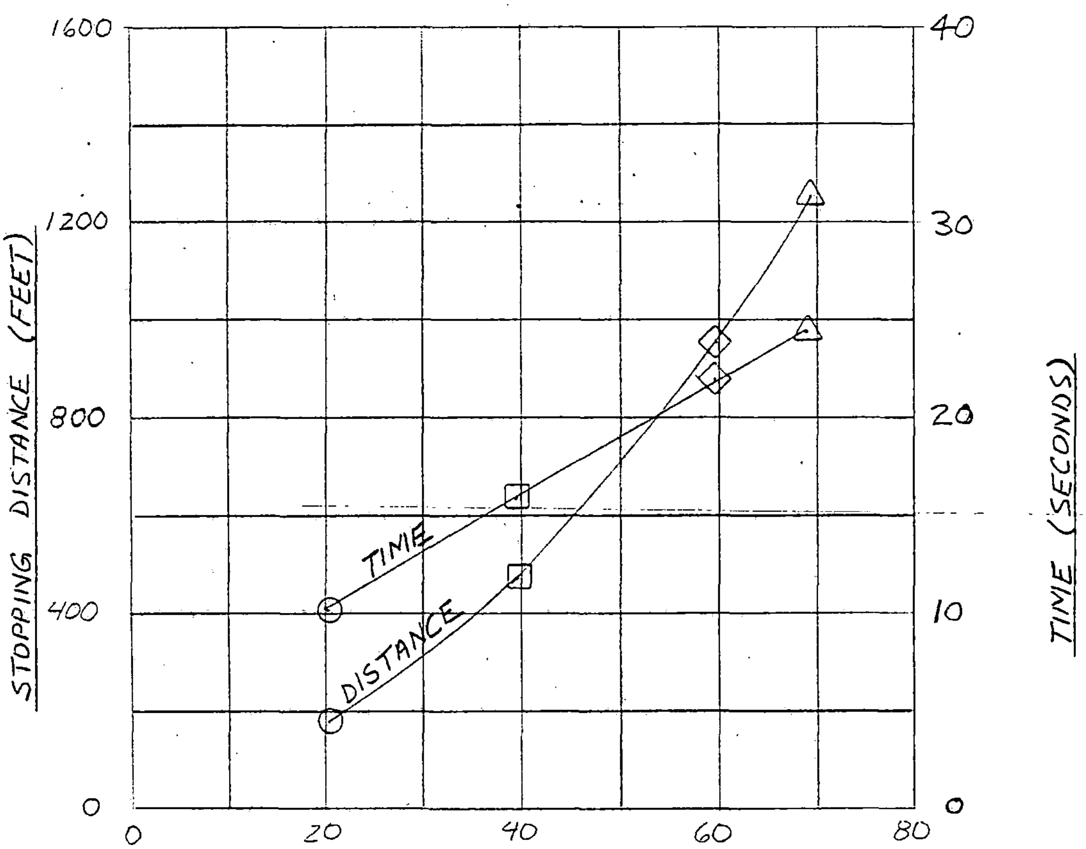


Figure 4–24. Blended-Braking Performance for a Two-Car Train at 98,000-Lb Car Weight

NOTES : 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 600 VOLTS, NOMINAL LINE VOLTAGE
4. 0 MA "P" SIGNAL
5. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 AND DOTX-5

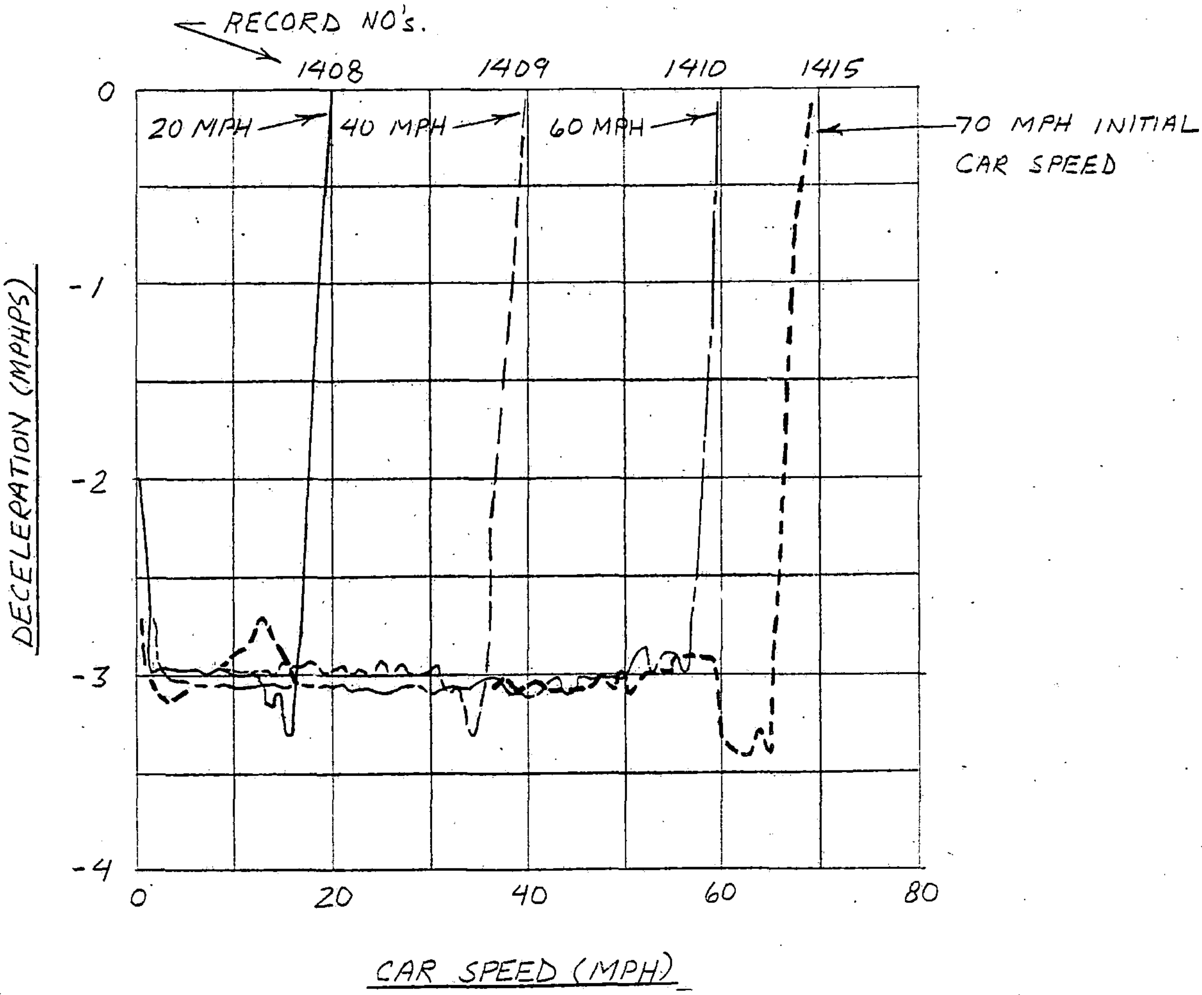


Figure 4–25. Deceleration Rate/Speed Profiles for a Two-Car Train at 98,000-Lb Car Weight

NOTES:
1) LEVEL TANGENT TRACK
2) 31 INCH WHEELS
3) ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO
DOTX-5 RECORD: 1127

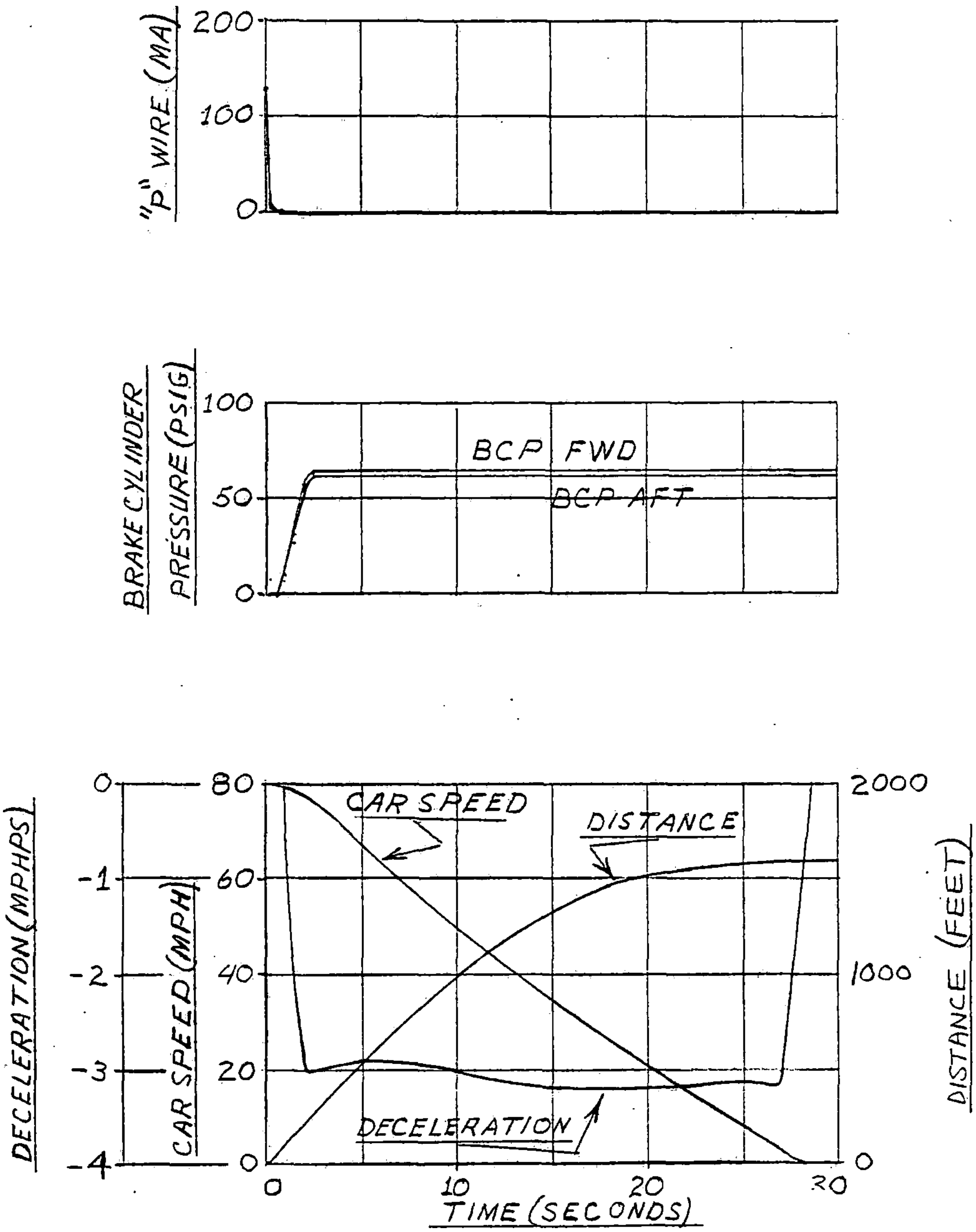


Figure 4–26. Deceleration Time History of Friction Braking at 98,000-Lb Car Weight

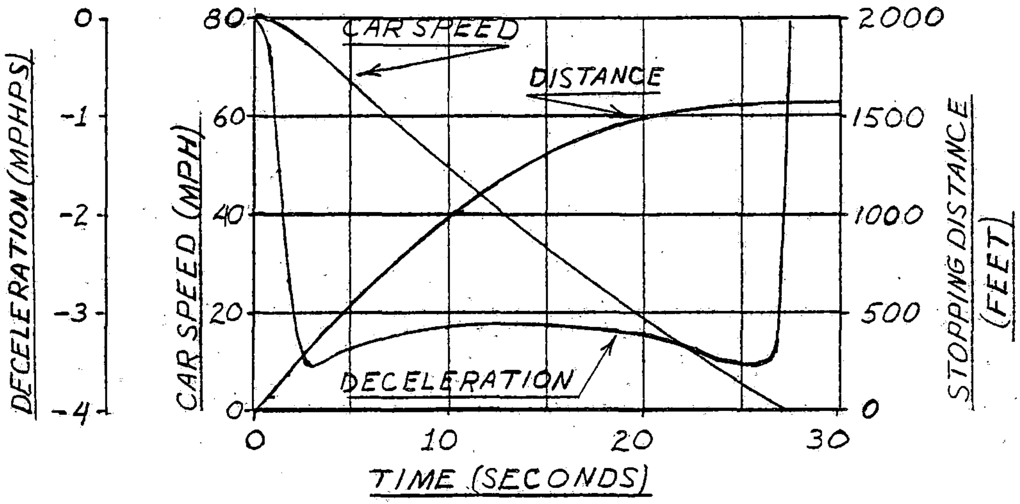
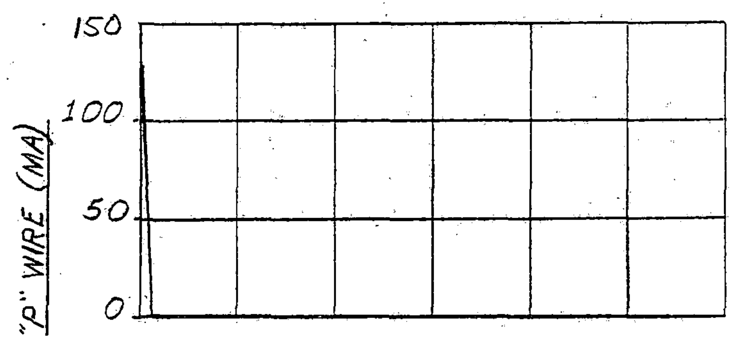


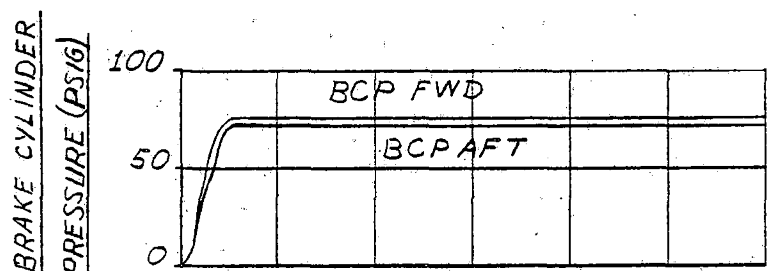
Figure 4—27. Deceleration Time History of Friction Braking at 130,400-Lb Car Weight

NOTES:

1) LEVEL, TANGENT TRACK
2) 31 INCH WHEELS
3) ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-5 RECORD: 992





NOTES:
1) LEVEL TANGENT TRACK
2) 31 INCH WHEELS
3) ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

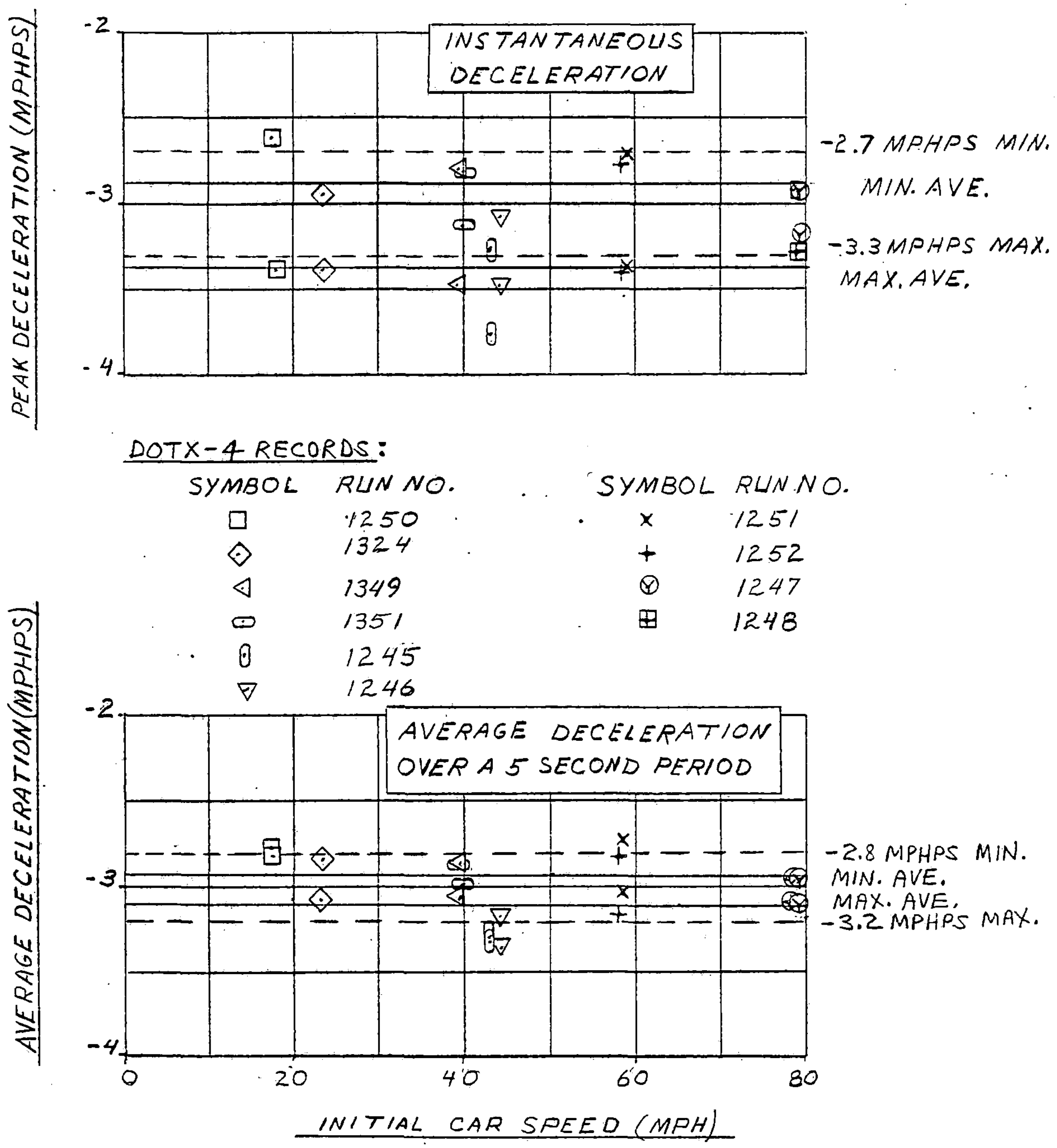


Figure 4–28. Deceleration Rate Characteristics of Friction Braking at 98,000-Lb Car Weight

NOTES:
1) LEVEL TANGENT TRACK
2) 31 INCH WHEELS
3) 0 MA "P" SIGNAL CONTROL INPUT
4) ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

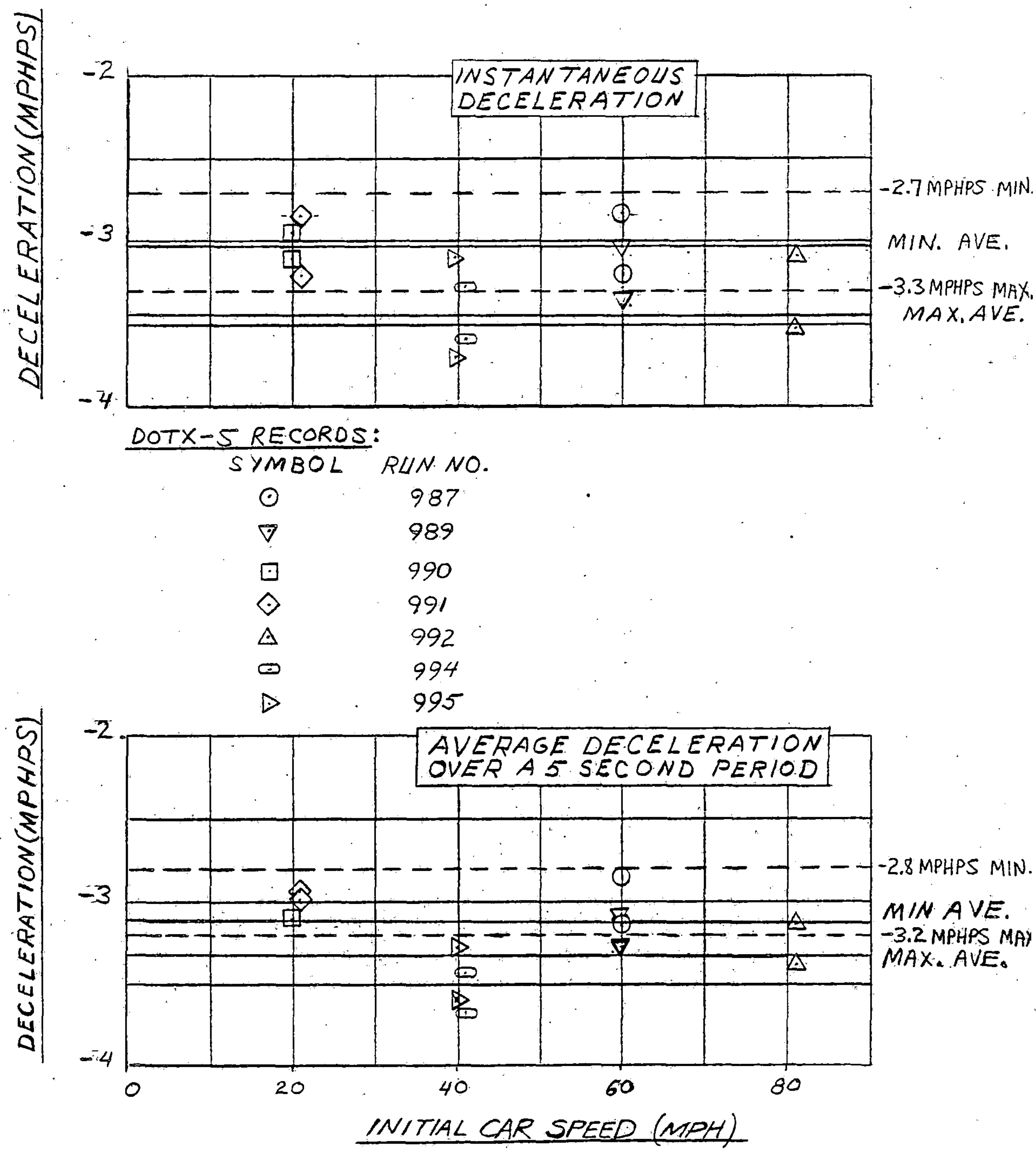


Figure 4–29. Deceleration Characteristics of Friction Braking at 130,400-Lb Car Weight

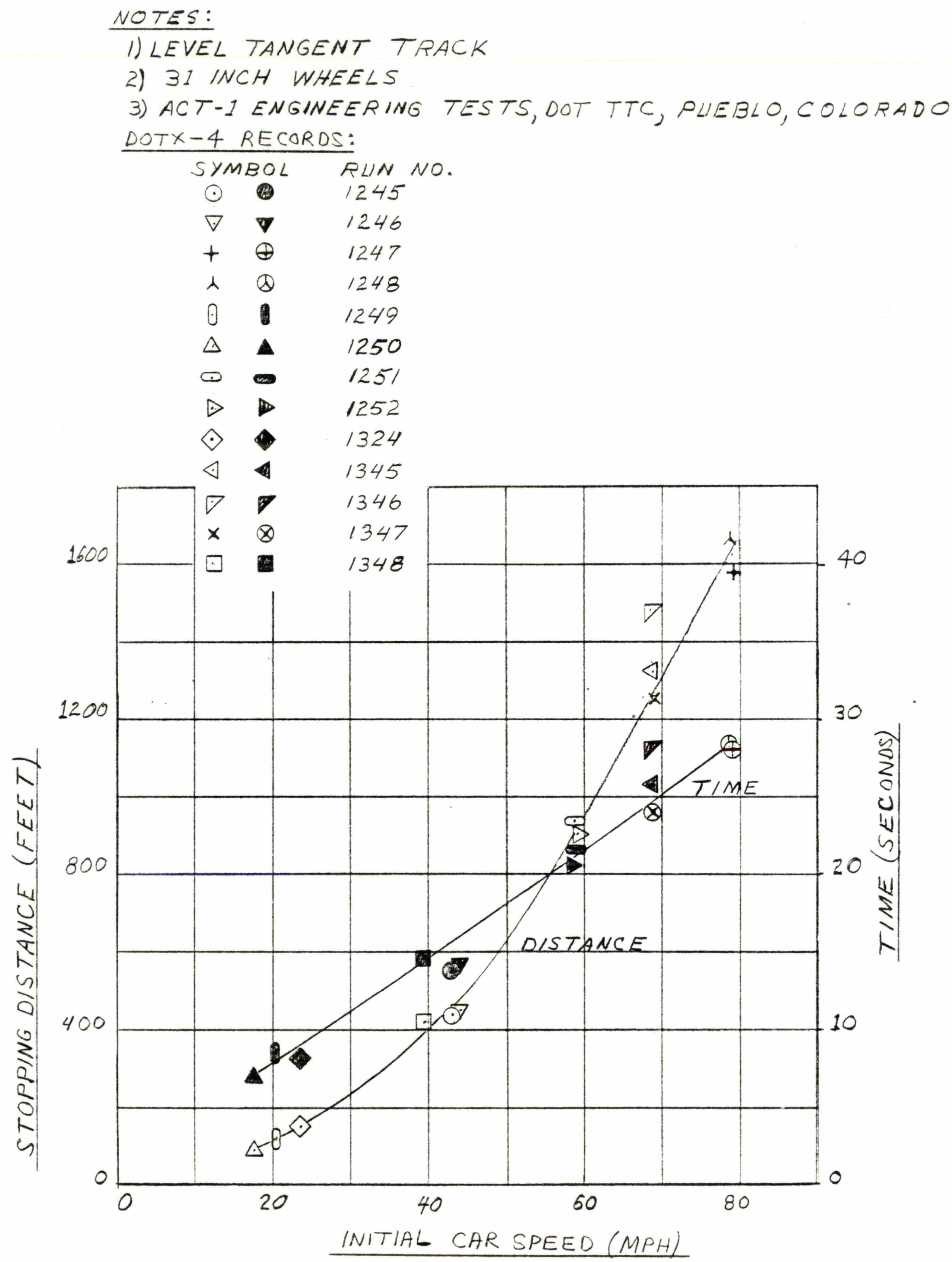


Figure 4–30. Friction Braking Performance at 98,000-Lb Car Weight

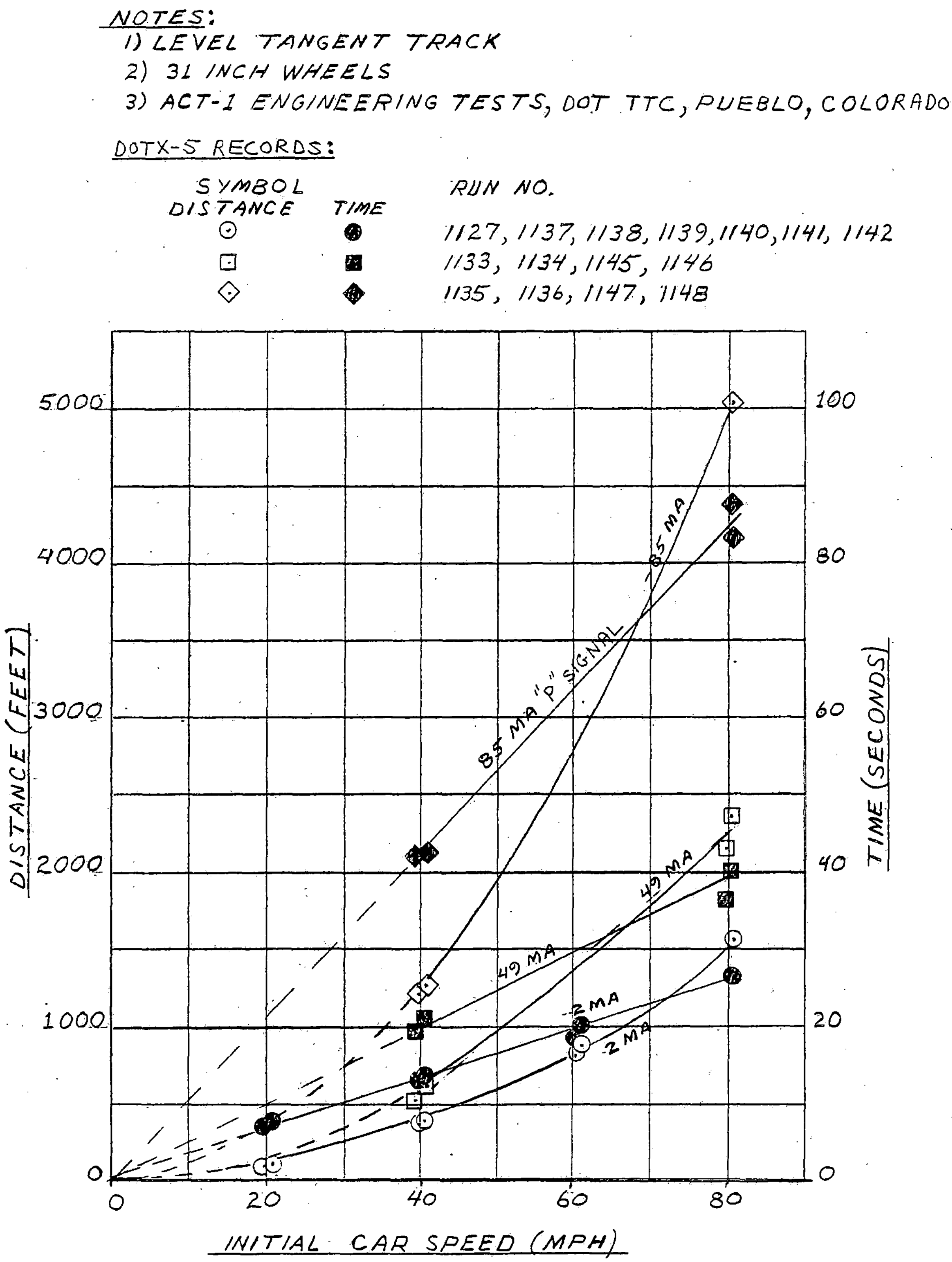


Figure 4–31. Friction Braking Performance for Various Control Inputs at 98,000-Lb Car Weight

NOTES:

1) LEVEL TANGENT TRACK
2) 31 INCH WHEELS
3) BRAKE ENTRY SPEED - 80 MPH
4) ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 RECORDS:

SYMBOL DISTANCE	SYMBOL TIME	RUN NO.
○	●	1240
+		1239
▽	▼	1241, 1242
⊡	■	1244
◇	◆	1247, 1248

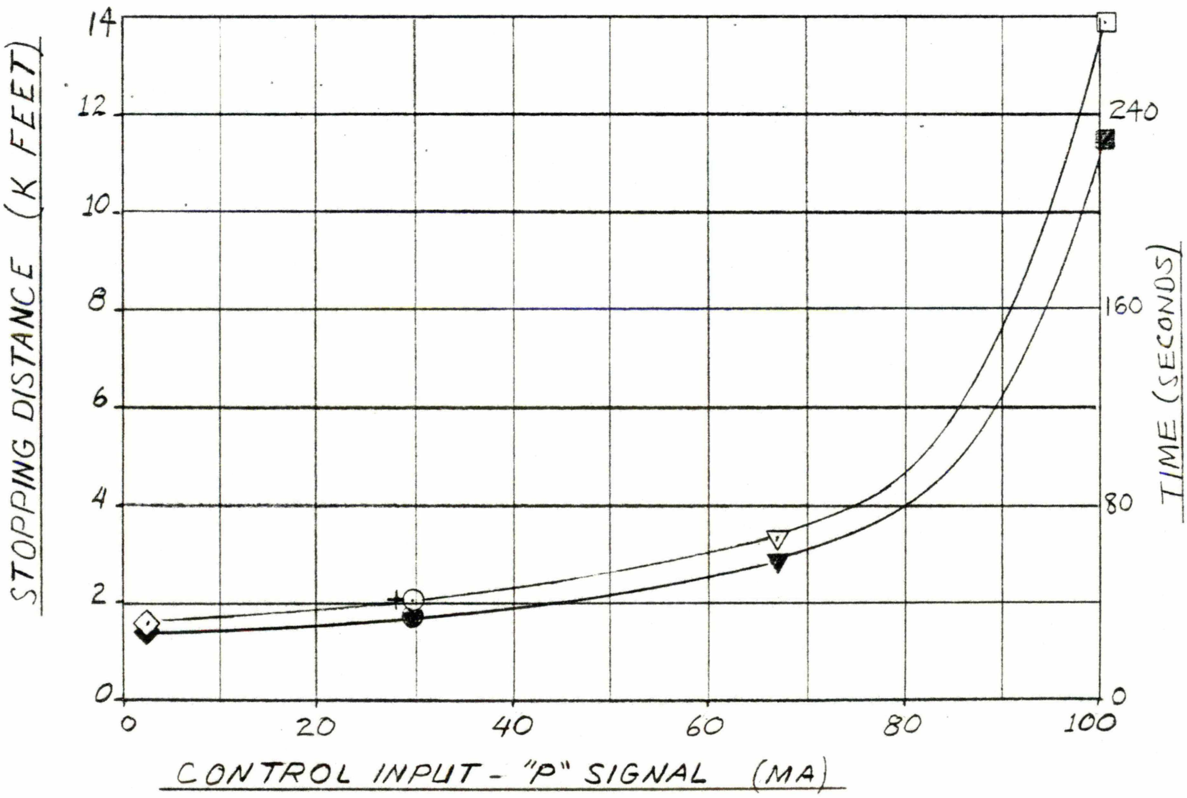


Figure 4—32. Friction Braking Performance for Various Control Inputs at 98,000-Lb Car Weight

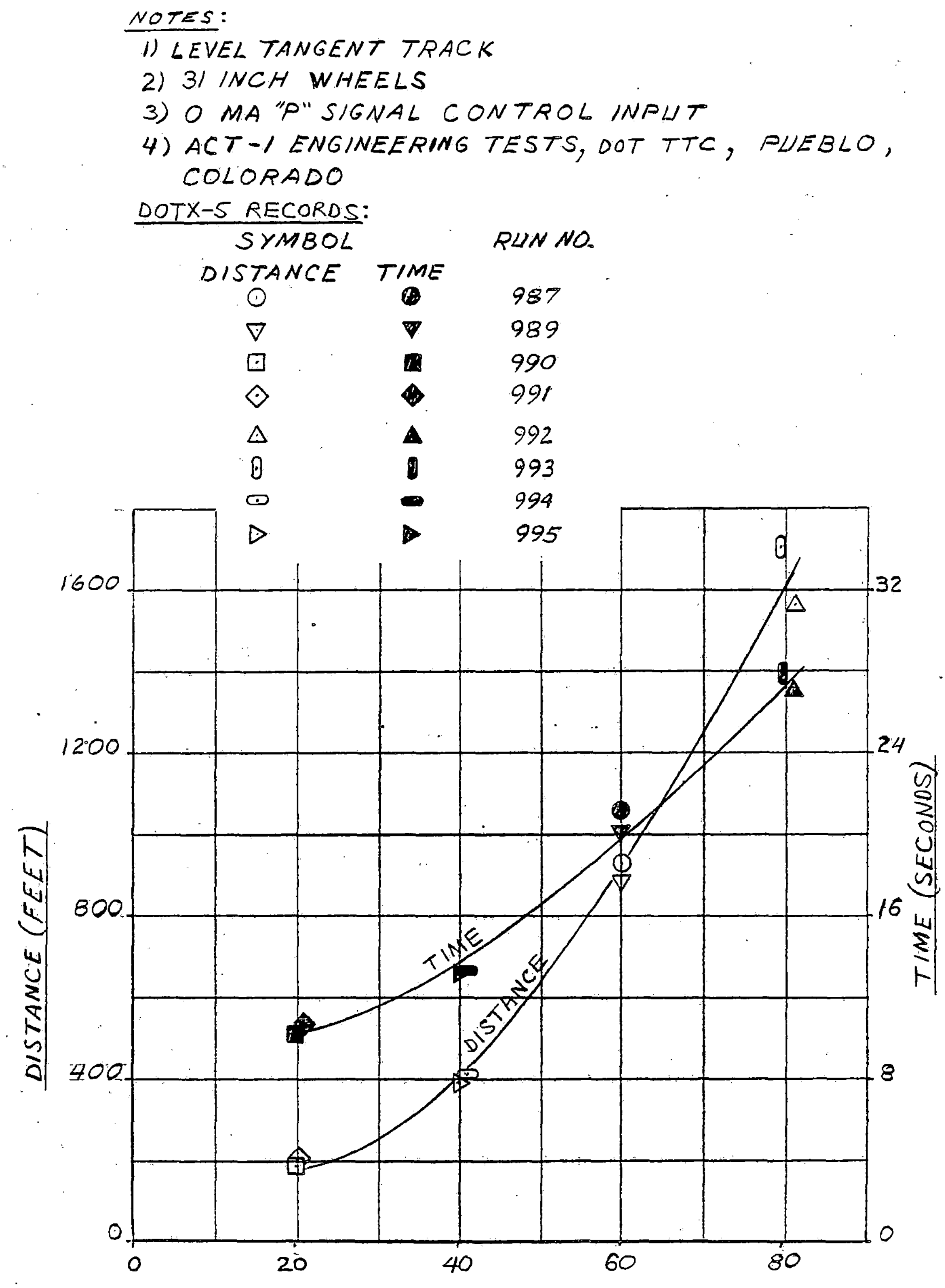


Figure 4–33. Friction Braking Performance for a One-Car Consist at 130,400-Lb Car Weight

NOTES:
1) LEVEL TANGENT TRACK
2) 31 INCH WHEELS
3) ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO
DOT X-4, DOT X-5

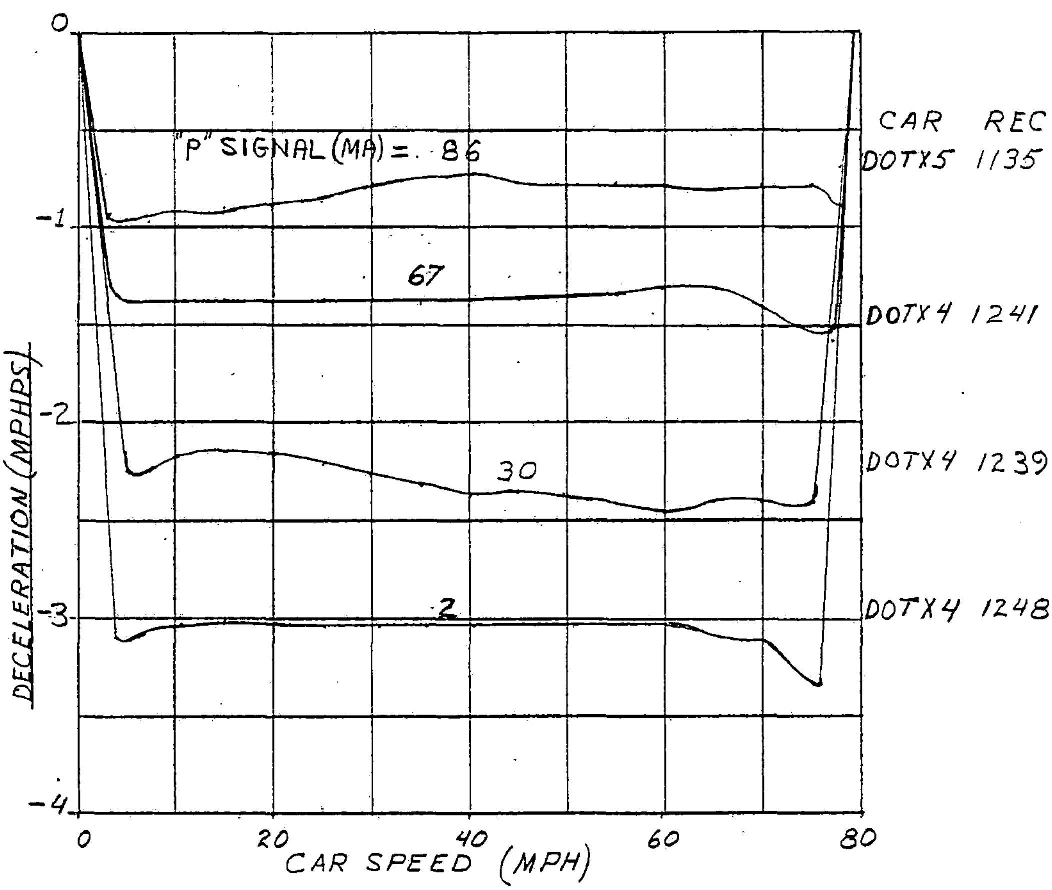


Figure 4–34. Deceleration Rate/Speed Profiles for Various Control Inputs of Friction Braking at 98,000-Lb Car Weight

NOTES:
1) LEVEL TANGENT TRACK
2) 31 INCH WHEELS
3) 0 MA "P" SIGNAL CONTROL INPUT
4) ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO
DOT X-4

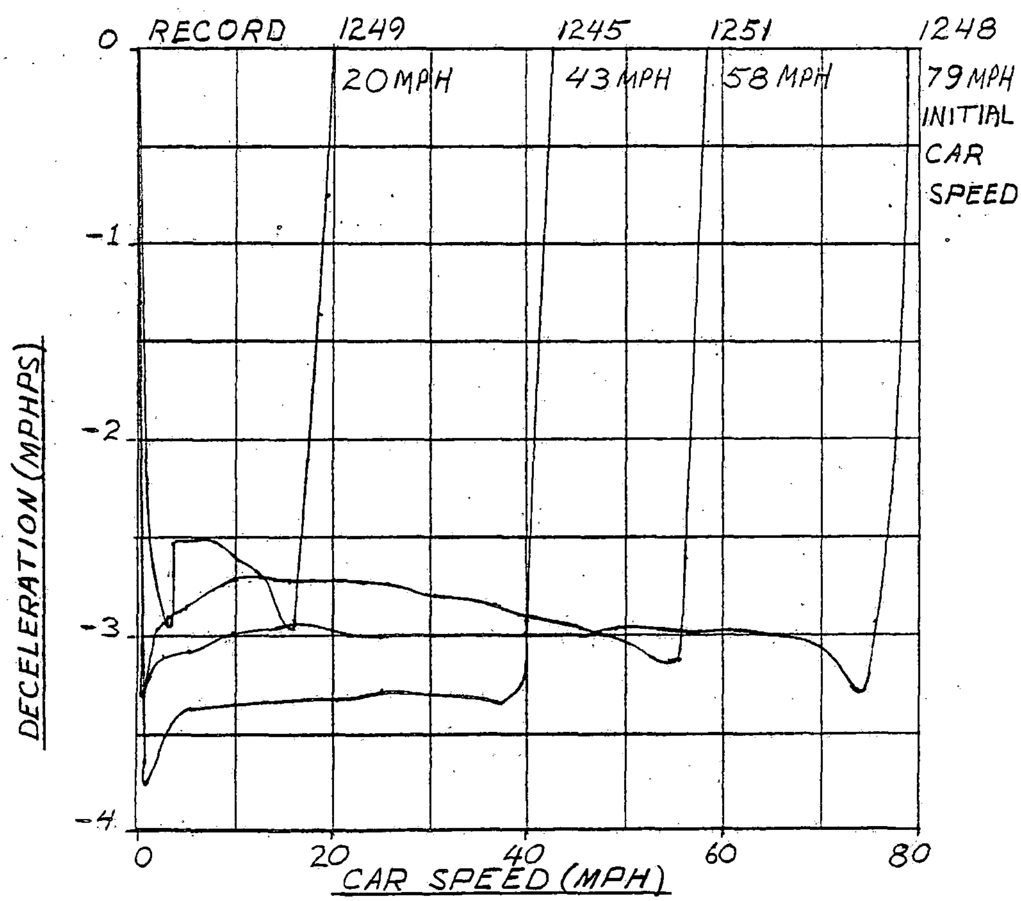


Figure 4—35. Deceleration Rate/Speed Profiles for Various Car Speeds of Friction Braking at 98,000-Lb Car Weight

NOTES:
1) LEVEL TANGENT TRACK
2) 31 INCH WHEELS
3) ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO
DOTX-5

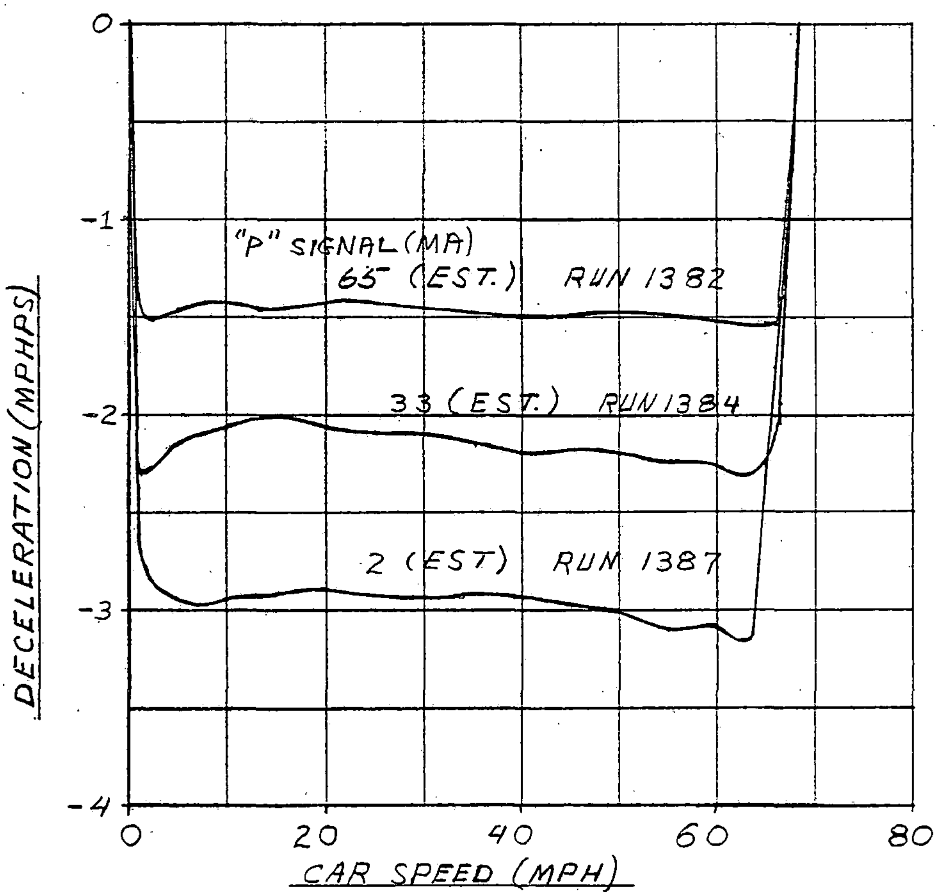


Figure 4–36. Deceleration Rate/Speed Profiles for Various Control Inputs of Friction Braking at 130,400-Lb Car Weight

NOTES:
1) LEVEL TANGENT TRACK
2) 31 INCH WHEELS
3) O MA "P" SIGNAL CONTROL INPUT
4) ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO
DOTX-5

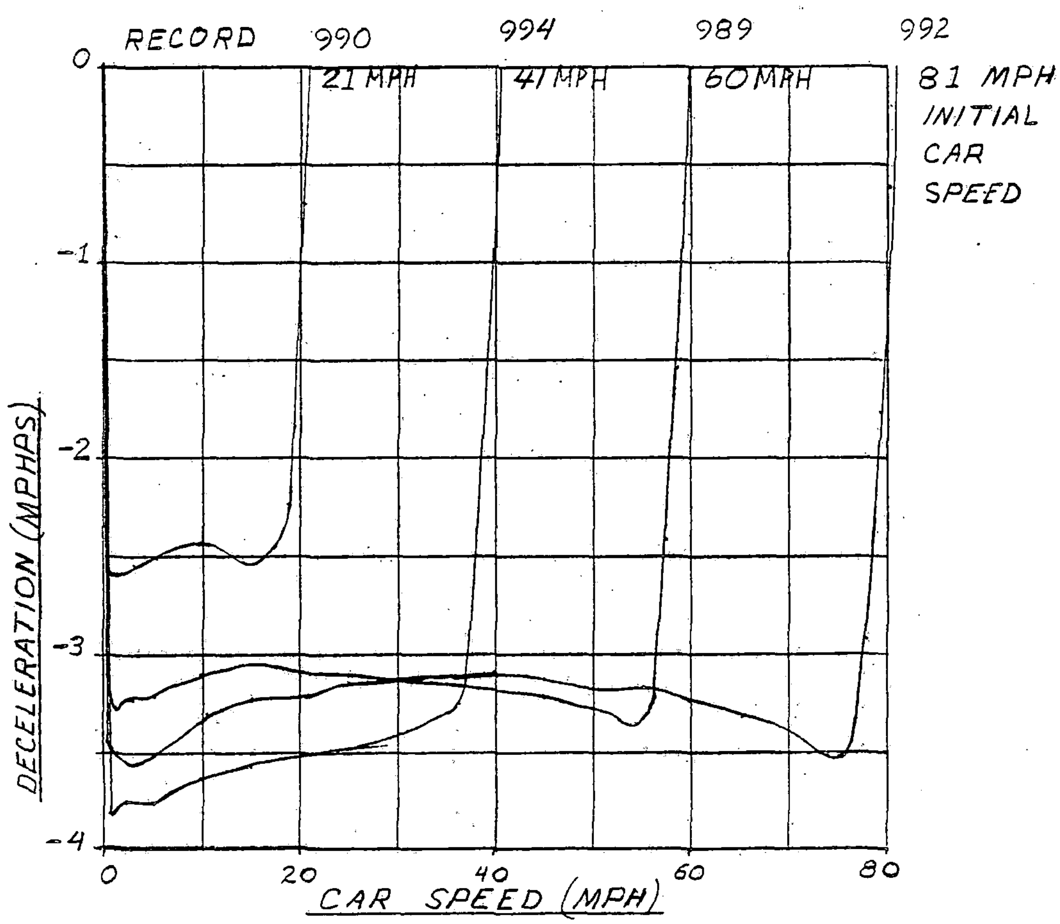


Figure 4—37. Deceleration Rate/Speed Profiles for Various Initial Speeds of Friction Braking at 130,400-Lb Car Weight

NOTES:

1) LEVEL TANGENT TRACK
2) 31 INCH WHEEL
3) BRAKE ENTRY SPEED, 80 MPH
4) ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 RECORDS:

SYMBOL	RUN NO.
⊕	1239
⊙	1240
⊡	1241
⊞	1242
◇ (dotted)	1243
◇ (crossed)	1244
△	1247, 1248

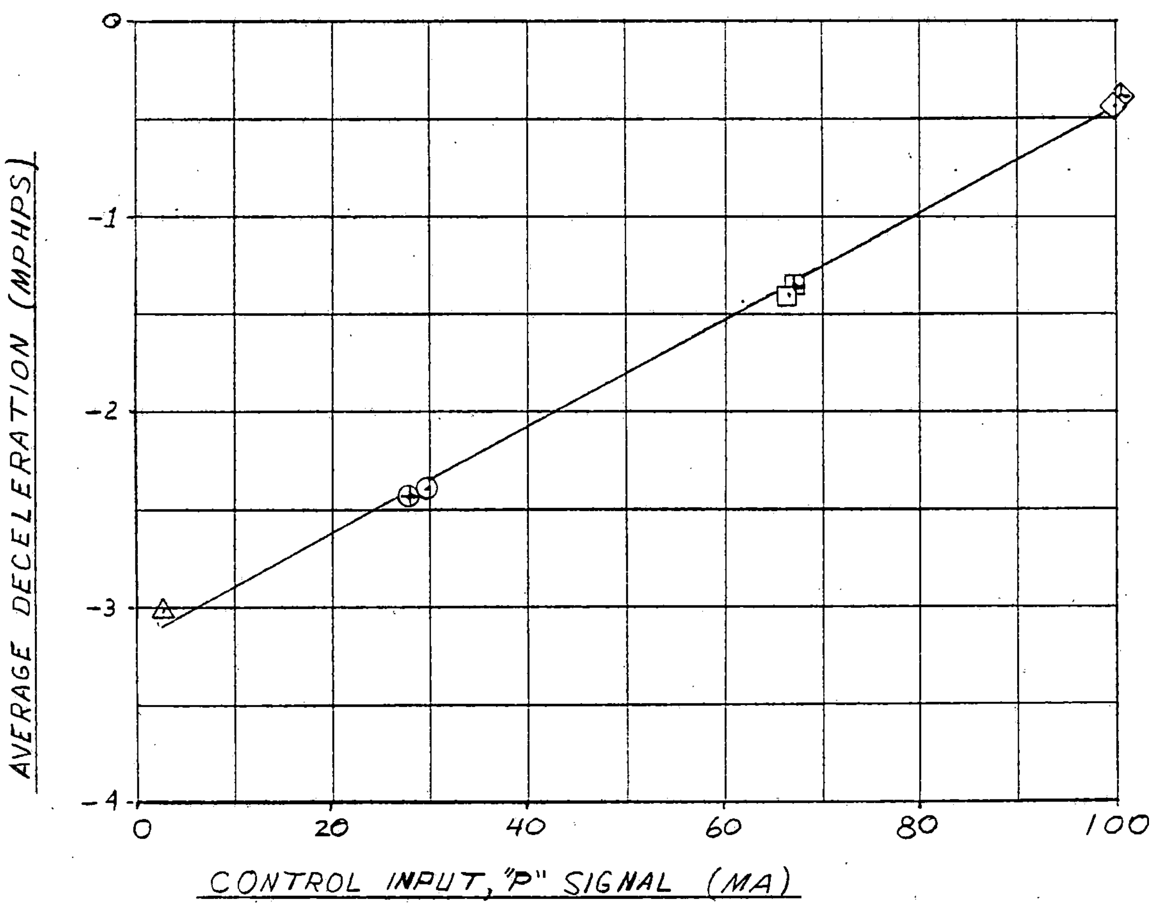


Figure 4—38. Control Linearity of Friction Braking Mode at 98,000-Lb Car Weight

NOTES:

1) LEVEL TANGENT TRACK
2) 31 INCH WHEELS
3) ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-5 RECORDS:

SYMBOL	RUN NO.
◁	1239
⊙	1240
⊡	1241
◇	1242
▷	1243
⊖	1244
⬯	1247
▽	1248

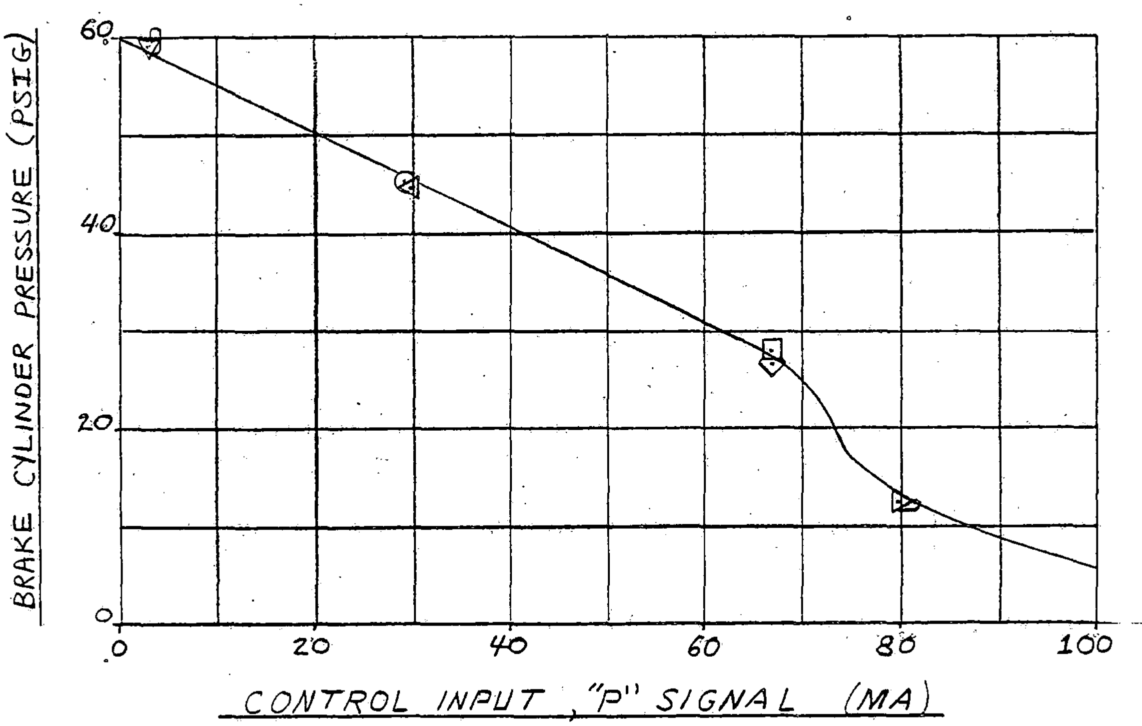


Figure 4—39. Variation of Brake Cylinder Pressure With Control Input of Friction Braking at 98,000-Lb Car Weight

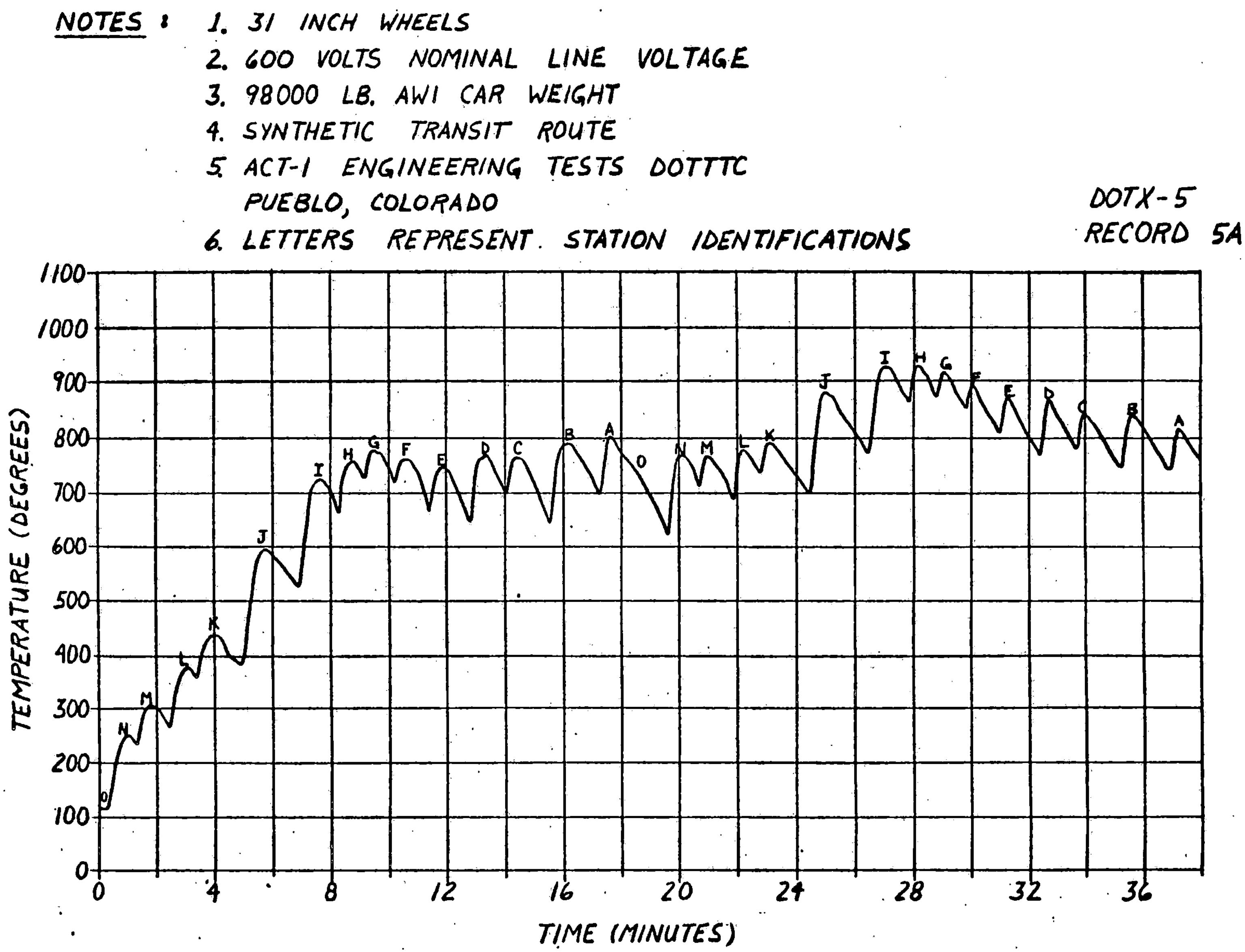


Figure 4–40. Brake Lining Temperature for Continuous Duty Cycle of Friction Braking

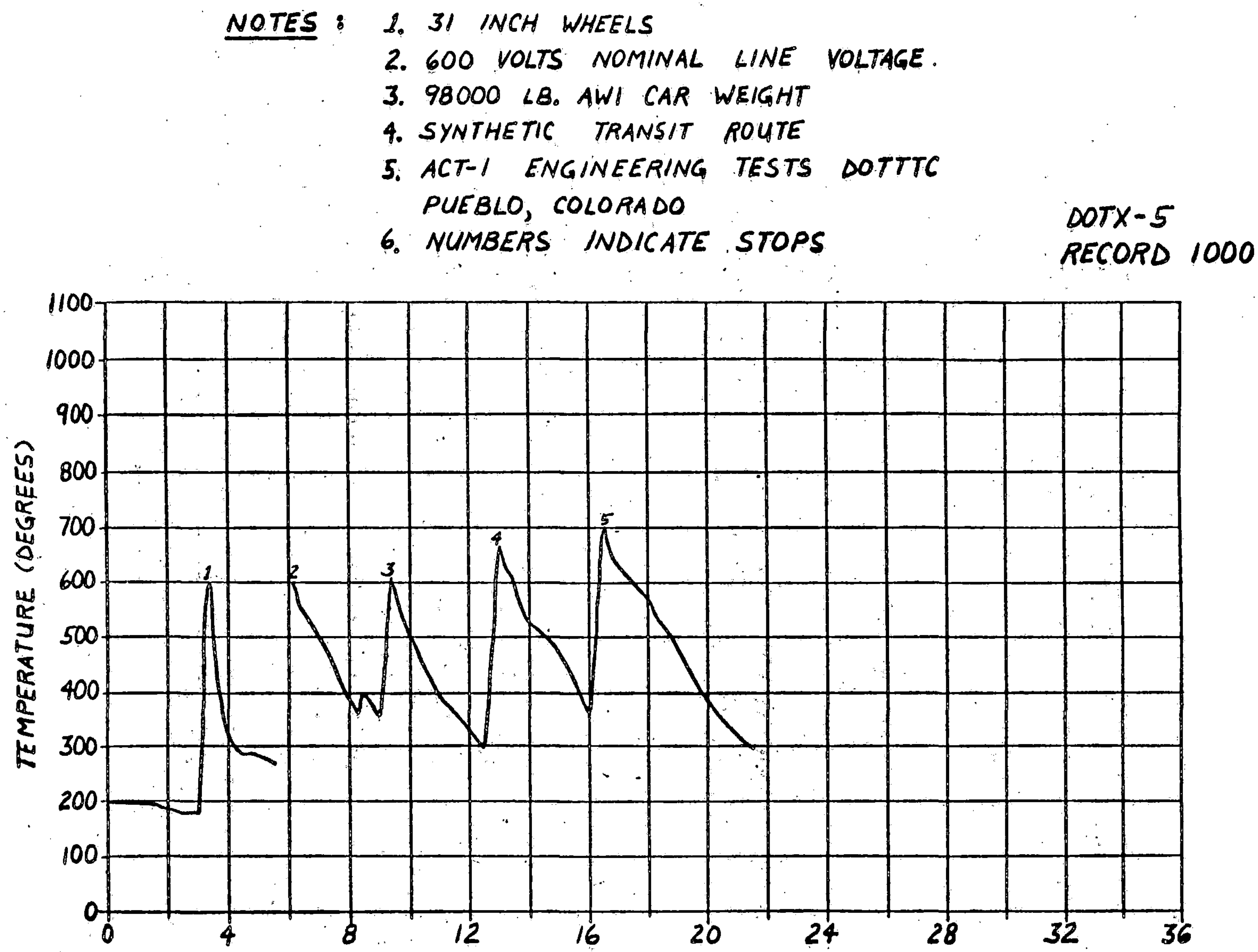


Figure 4–41. Brake Lining Temperature for Emergency Duty Cycle of Friction Braking

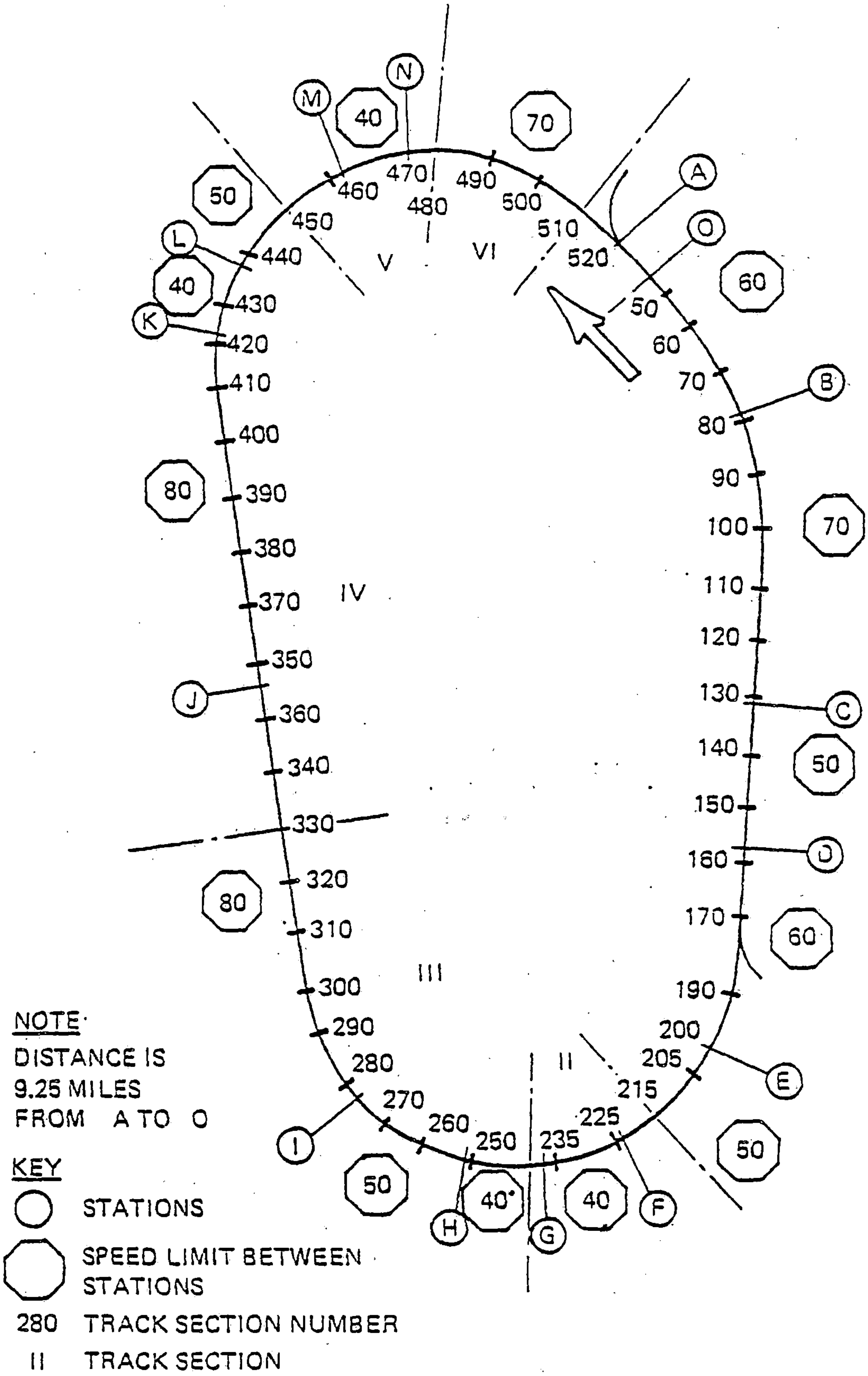


Figure 4—42. ACT-1 Synthetic Transit Route

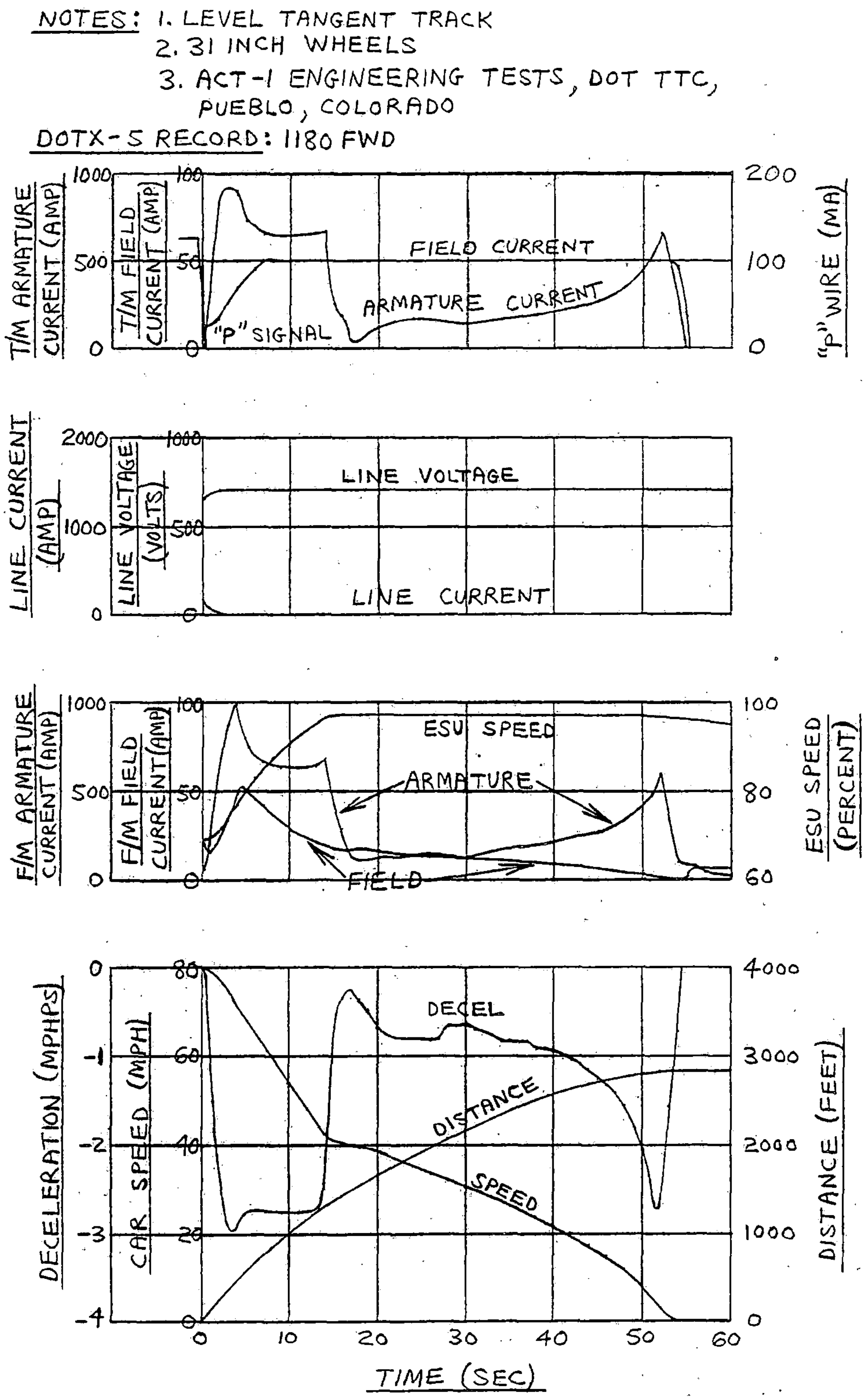


Figure 4—43. Deceleration Time History of Electric Braking at 98,000-Lb Car Weight and 80-Mph Initial Car Speed

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-5 RECORD: 1182 FWD

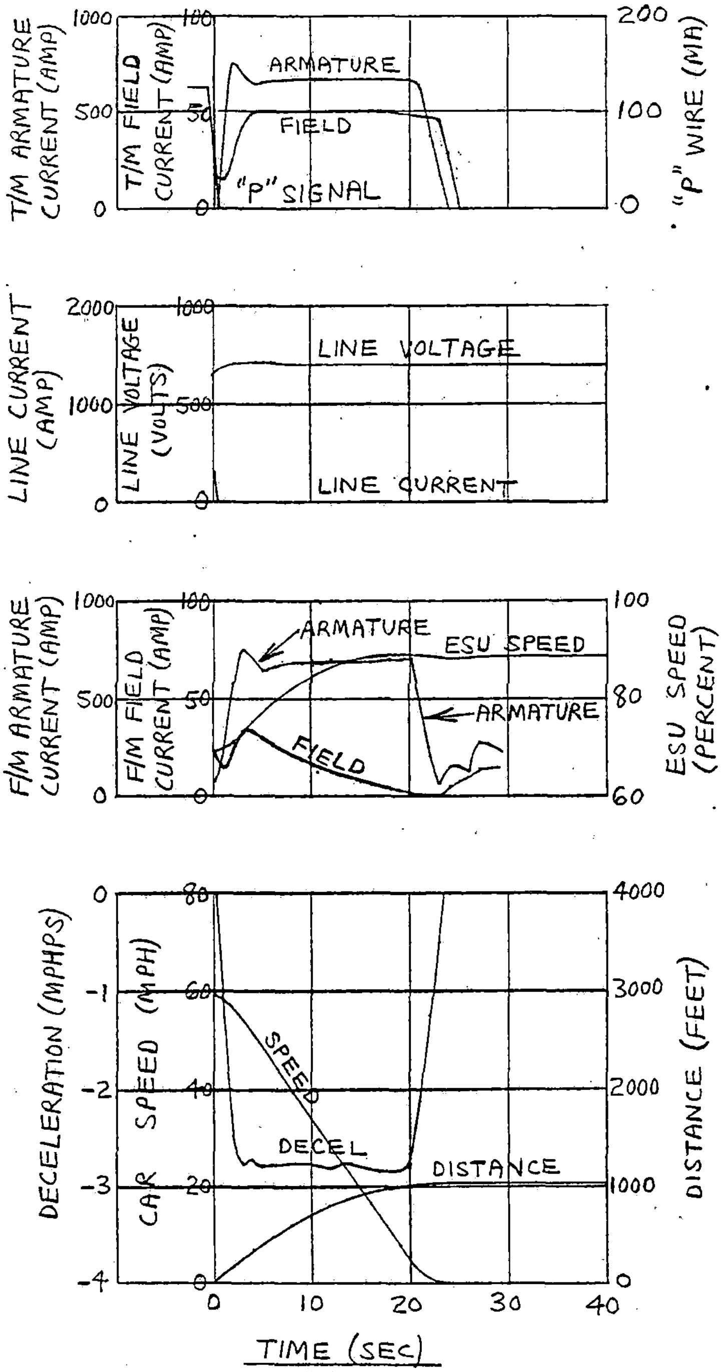


Figure 4—44. Deceleration Time History of Electric Braking at 98,000-Lb Car Weight and 60-Mph Initial Car Speed

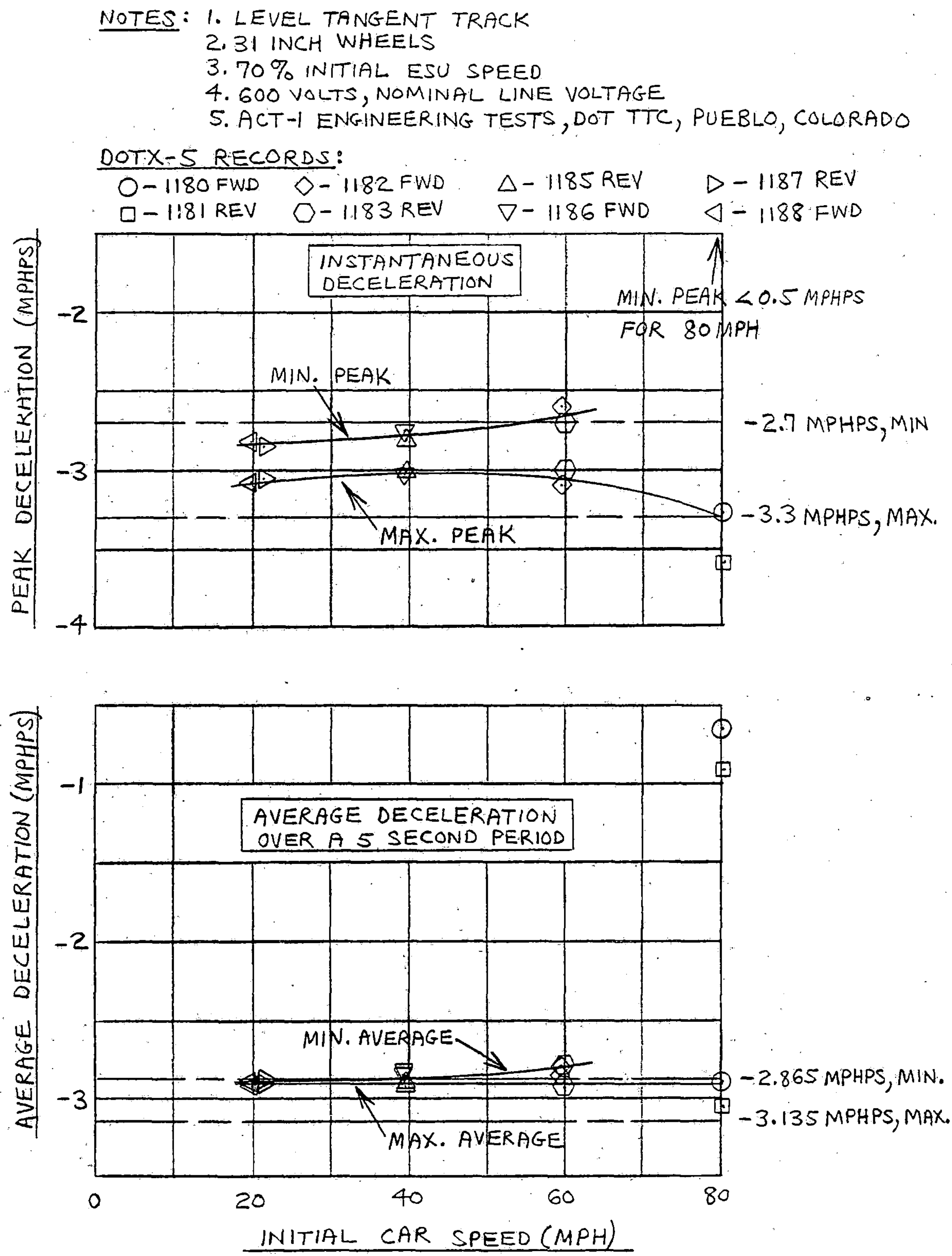


Figure 4—45. Deceleration Rate Characteristics of Electric Braking at 98,000-Lb Car Weight

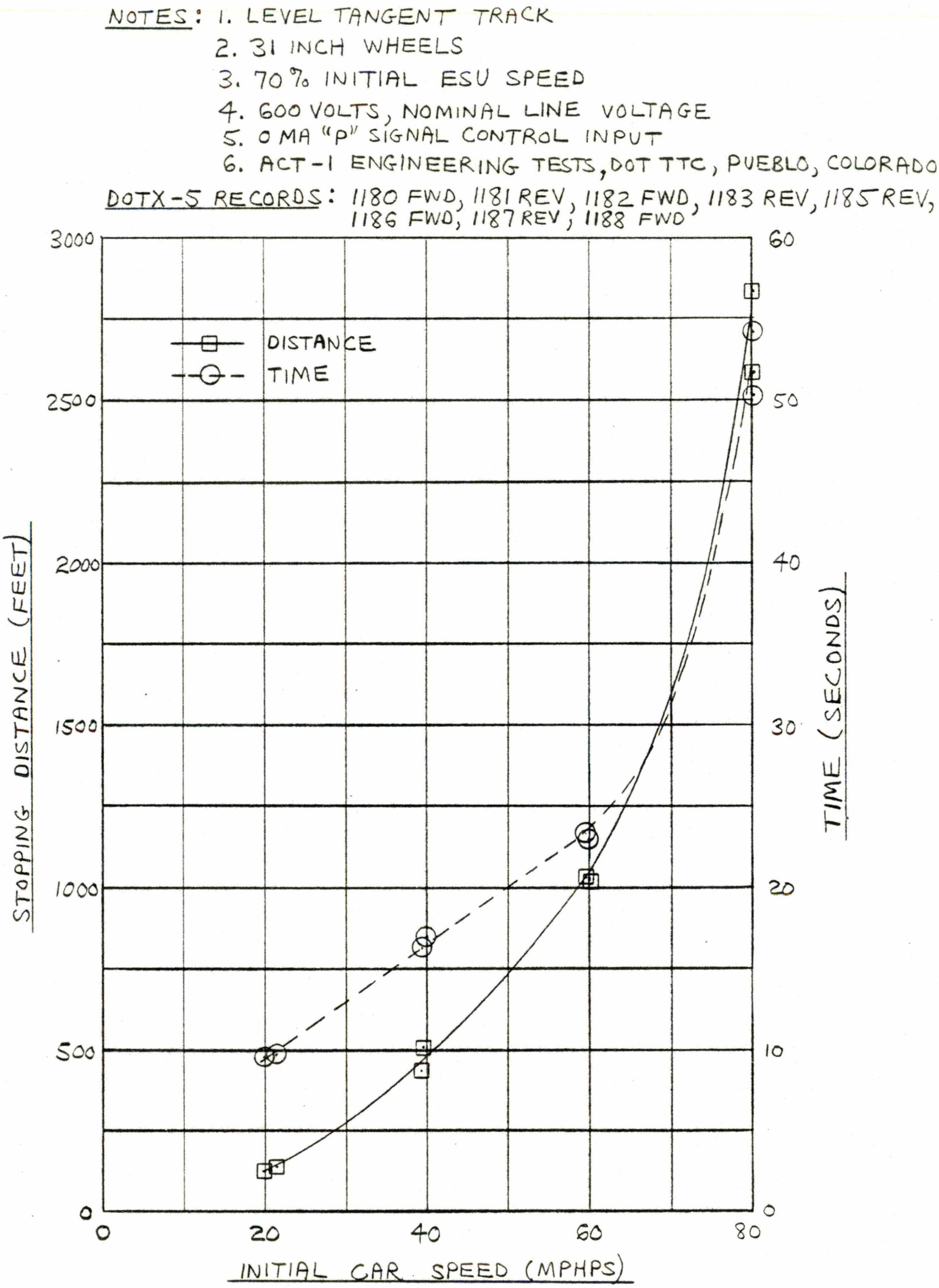


Figure 4—46. Electric Braking Performance at 98,000-Lb Car Weight

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 70% INITIAL ESU SPEED
4. 600 VOLTS, NOMINAL LINE VOLTAGE
5. 0 MA "P" SIGNAL CONTROL INPUT
6. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-5 RECORDS:

1180 FWD – 80.1 MPH ————
1182 FWD – 59.7 MPH – – – – –
1186 FWD – 39.3 MPH —— – ——
1188 FWD – 19.8 MPH —— - - ——

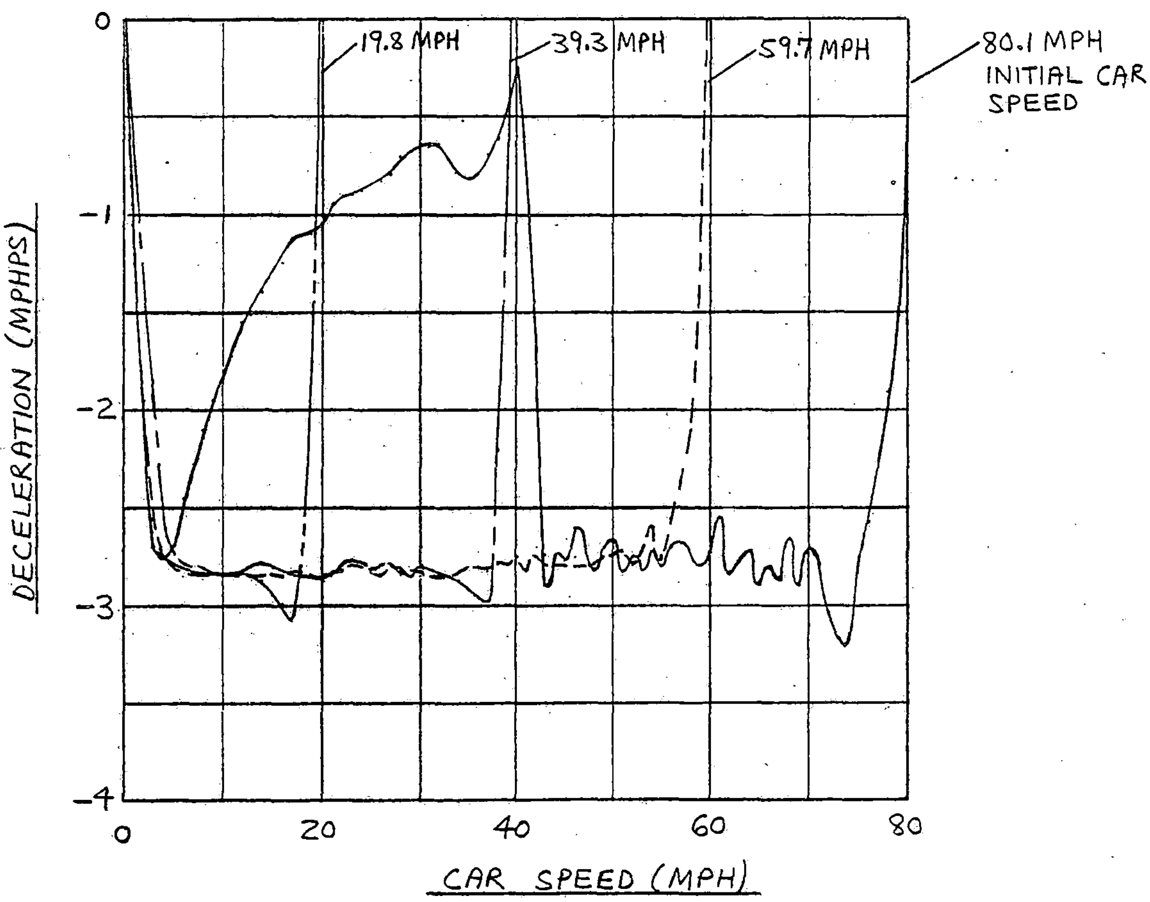


Figure 4–47. Deceleration Rate/Speed Profiles for Various Initial Car Speeds of Electric Braking at 98,000-Lb Car Weight

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 RECORD: 1257 FWD

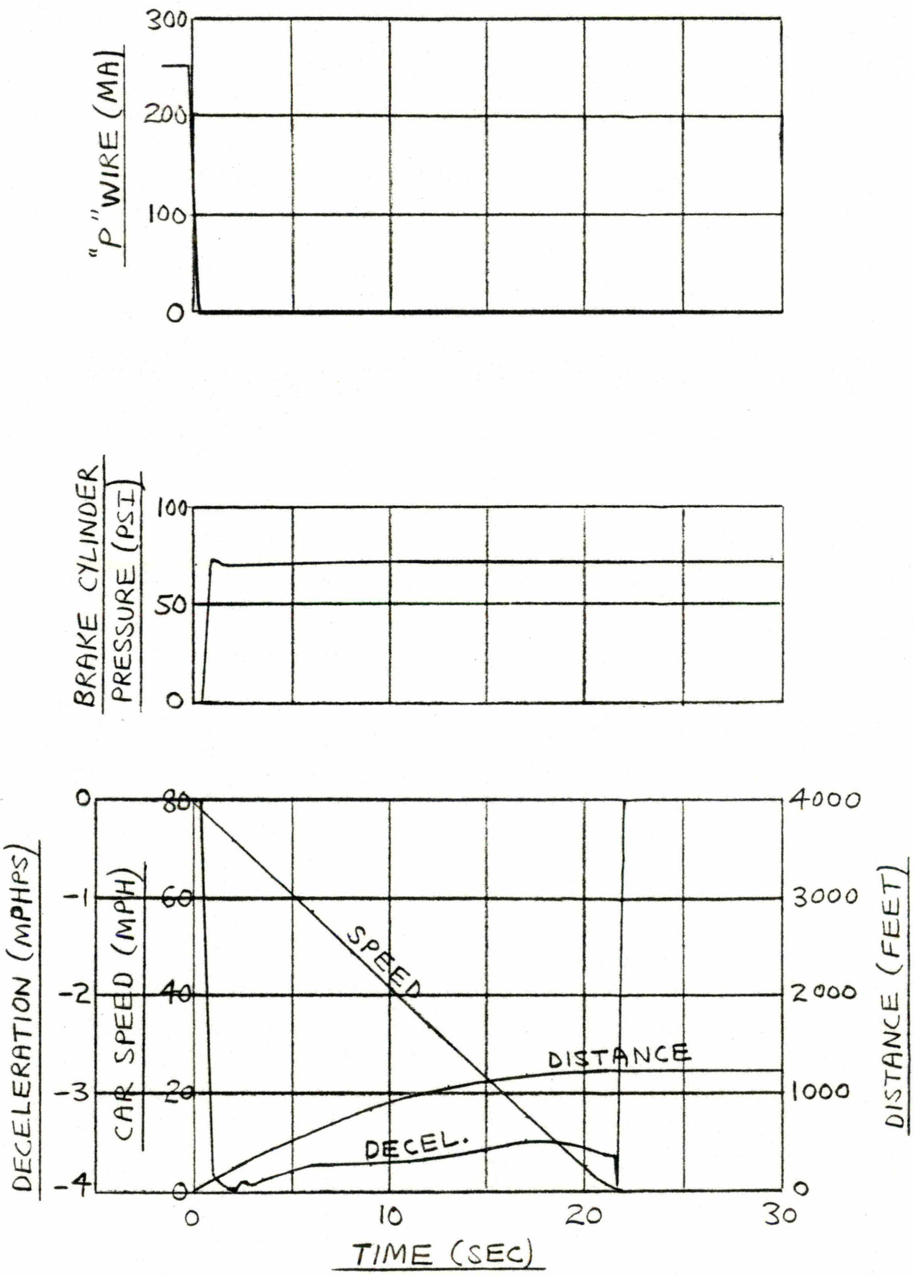


Figure 4—48. Deceleration Time History of Emergency Braking at 98,000-Lb Car Weight

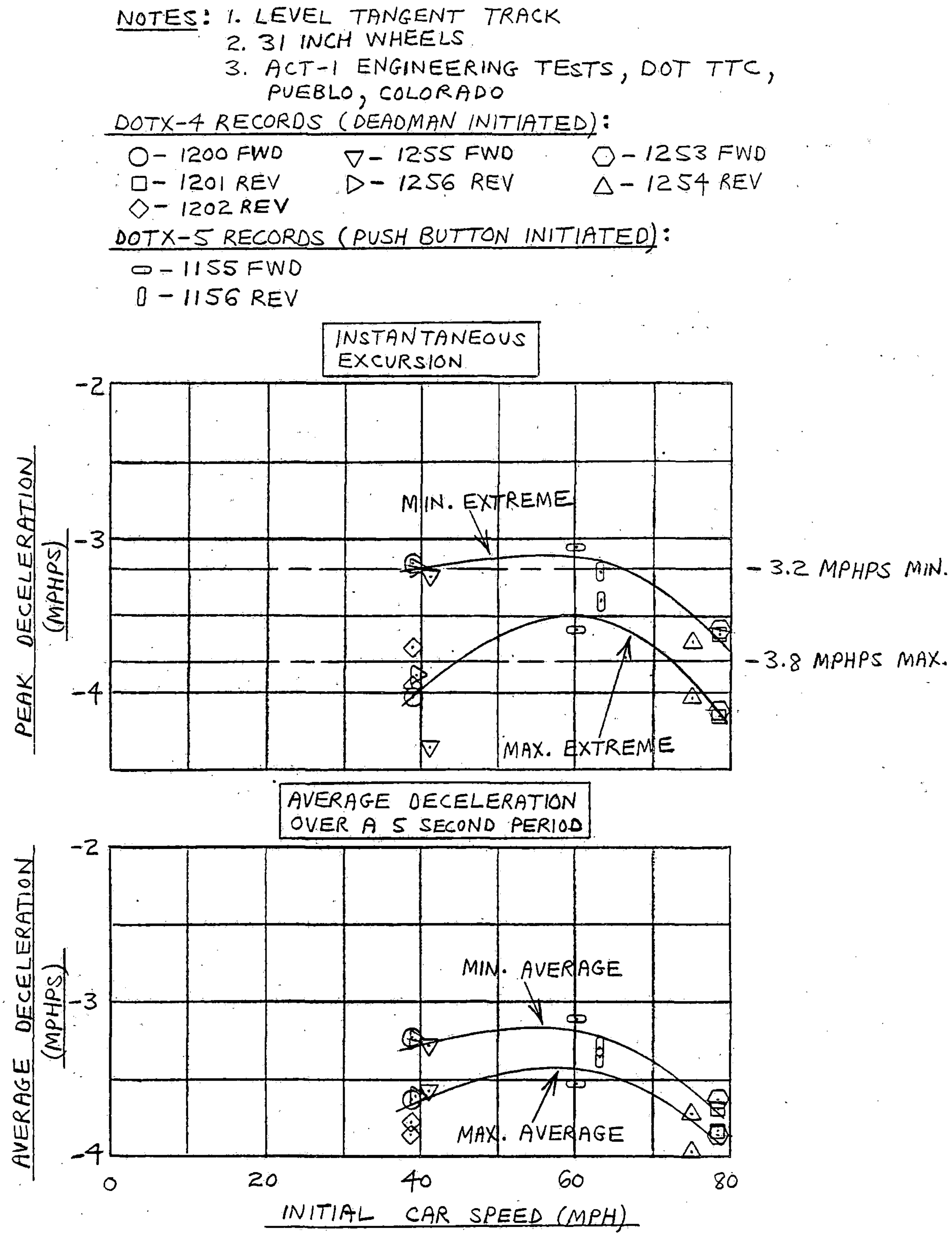


Figure 4–49. Deceleration Rate Characteristics of Emergency Braking at 98,000-Lb Car Weight

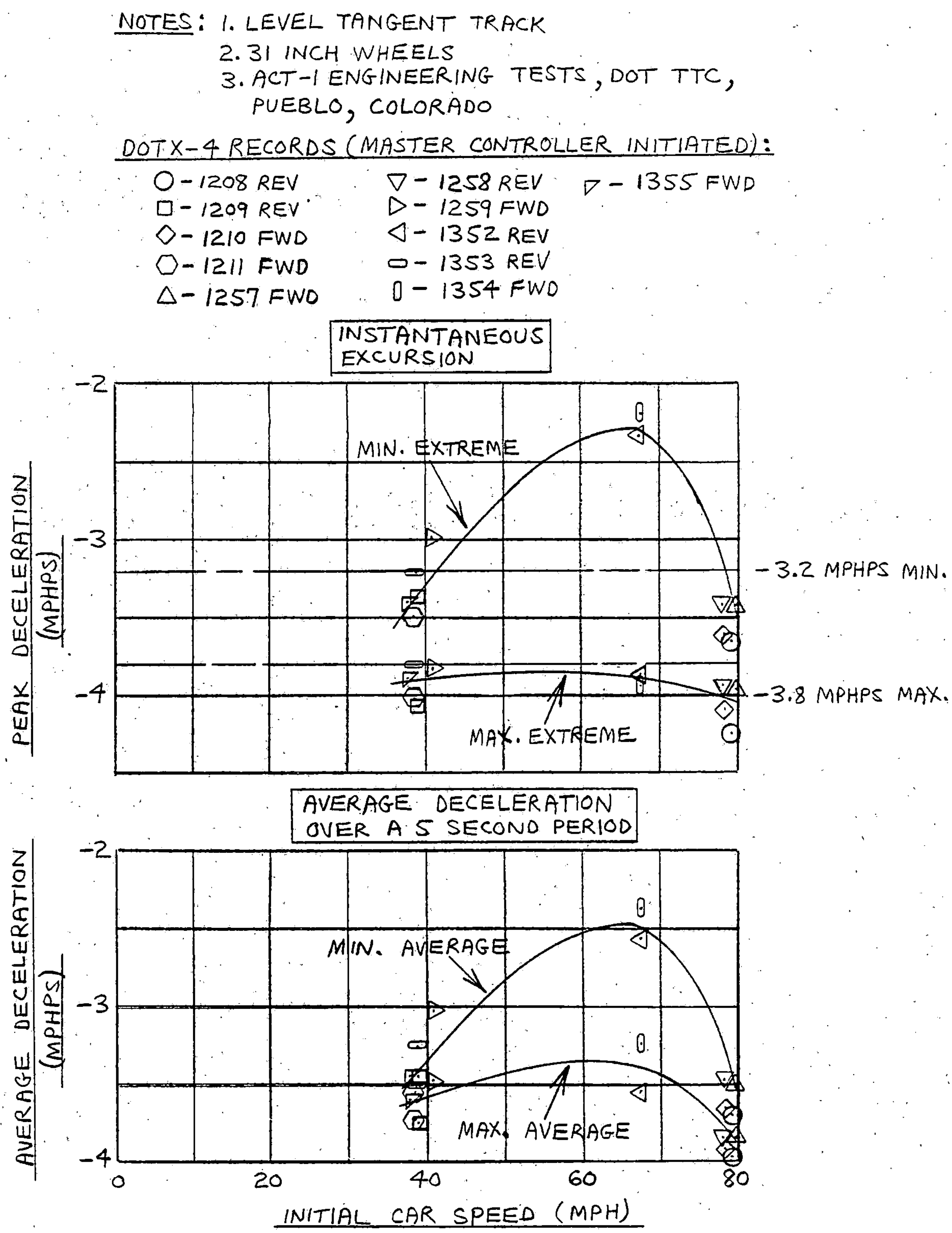


Figure 4—50. Deceleration Rate Characteristics of Emergency Braking at 98,000-Lb Car Weight

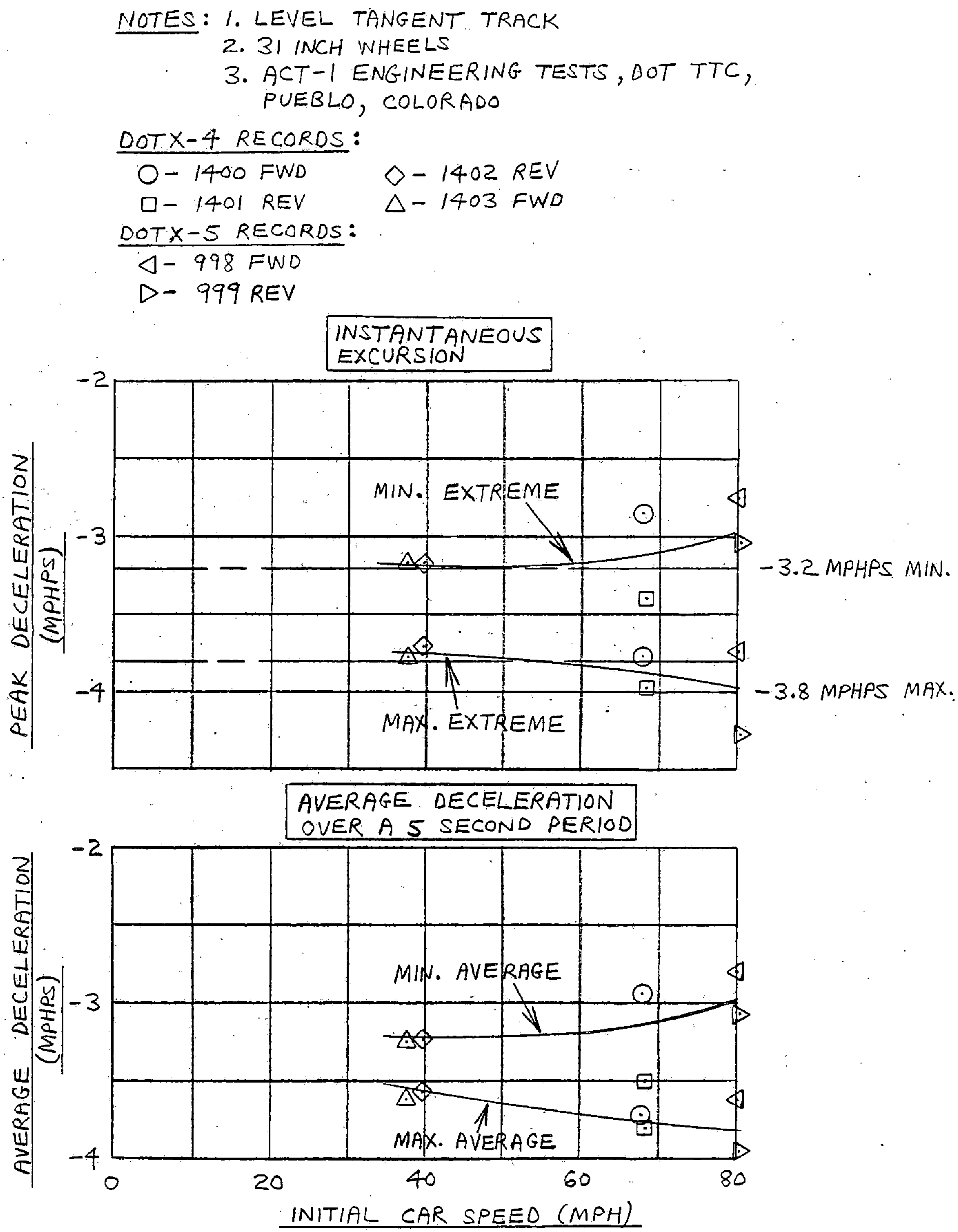


Figure 4–51. Deceleration Rate Characteristics of Emergency Braking at 130,400-Lb Car Weight

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. ACT-1 ENGINEERING TESTS, DOT TTC,
PUEBLO, COLORADO

DOTX-4 RECORDS: 1253 FWD, 1255 FWD, 1400 FWD, 1403 FWD

DOTX-5 RECORDS: 998 FWD, 999 REV, 874 REV, 875 FWD,
1153 FWD, 1154 REV, 1155 FWD, 1156 REV

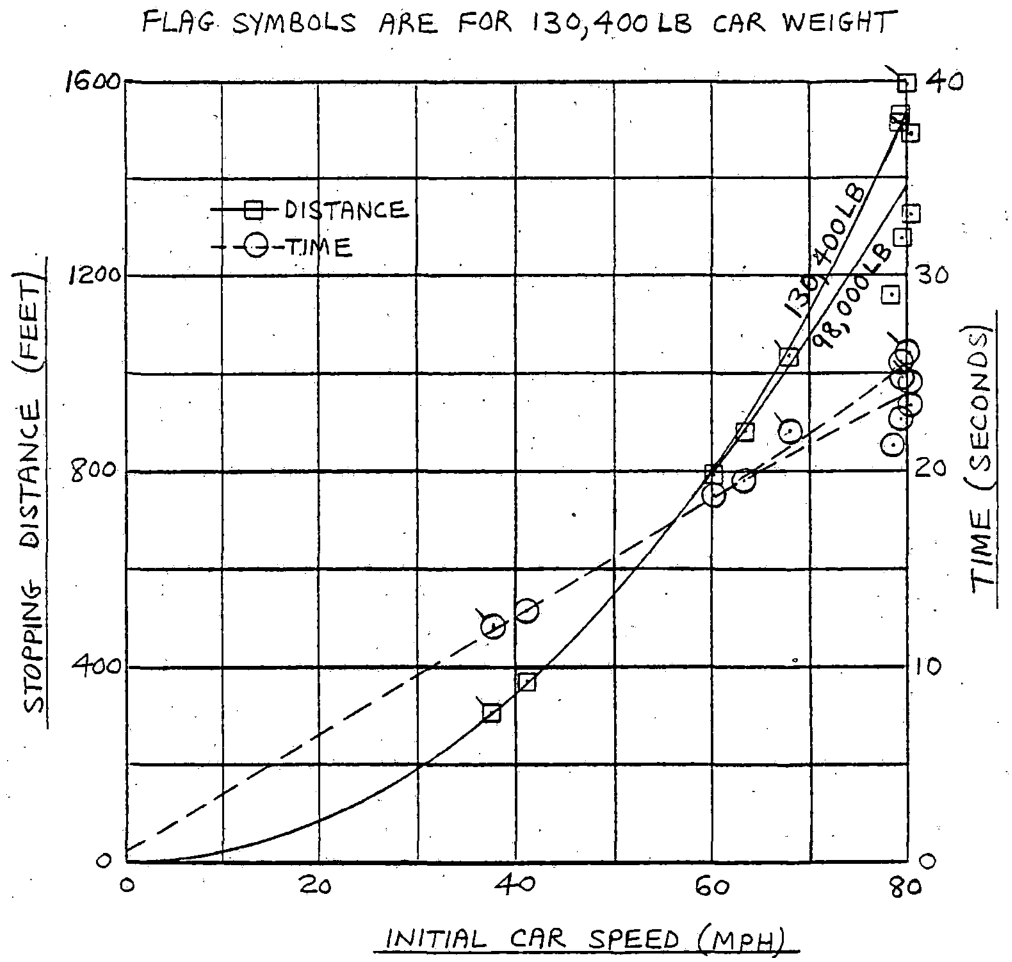


Figure 4—52. Emergency Braking Performance at 98,000-Lb and 130,400-Lb Car Weights

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 RECORDS:

1211 FWD - 38.5 MPH

1257 FWD - 79.9 MPH

DOTX-5 RECORDS:

1155 FWD - 60.2 MPH

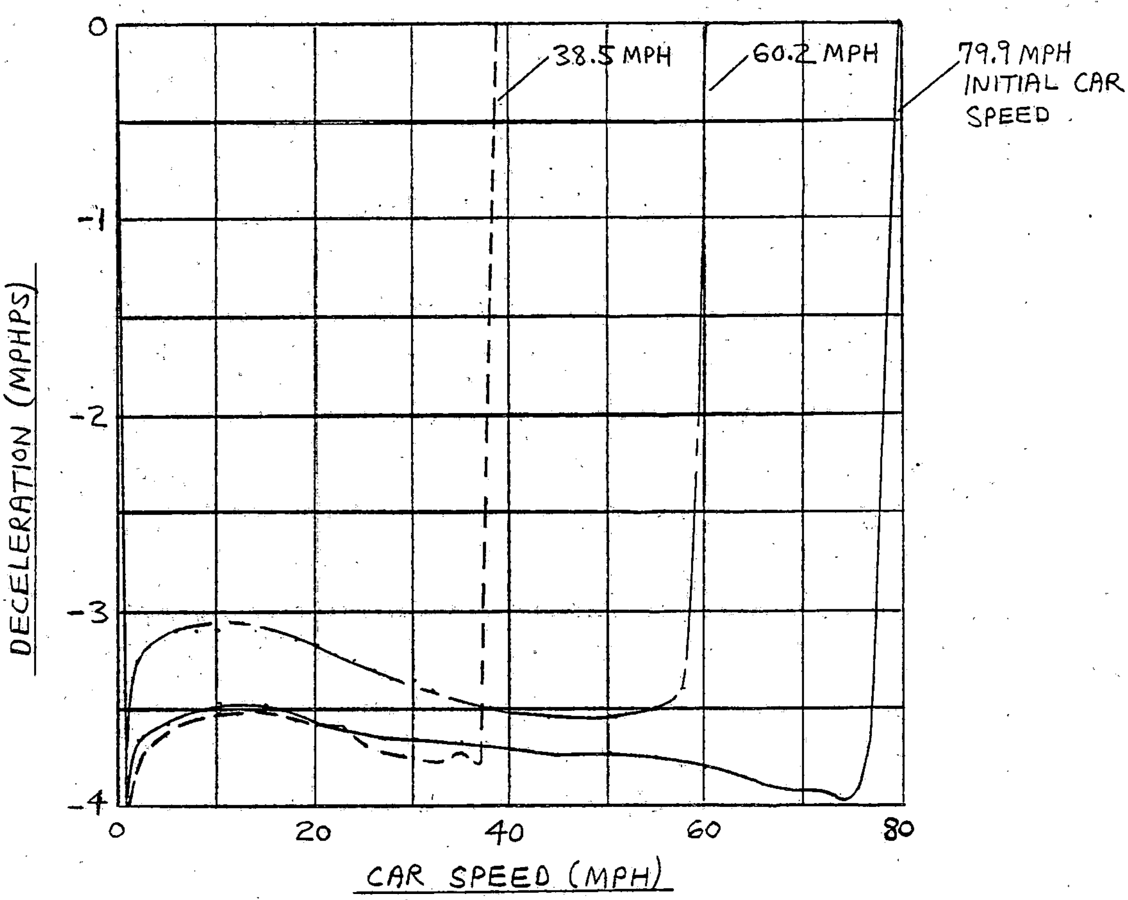


Figure 4—53. Deceleration Rate/Speed Profiles for Various Initial Car Speeds of Emergency Braking at 98,000-Lb Car Weight

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 RECORDS:

1400 FWD - 68.0 MPH ————
1403 FWD - 37.7 MPH - - - -

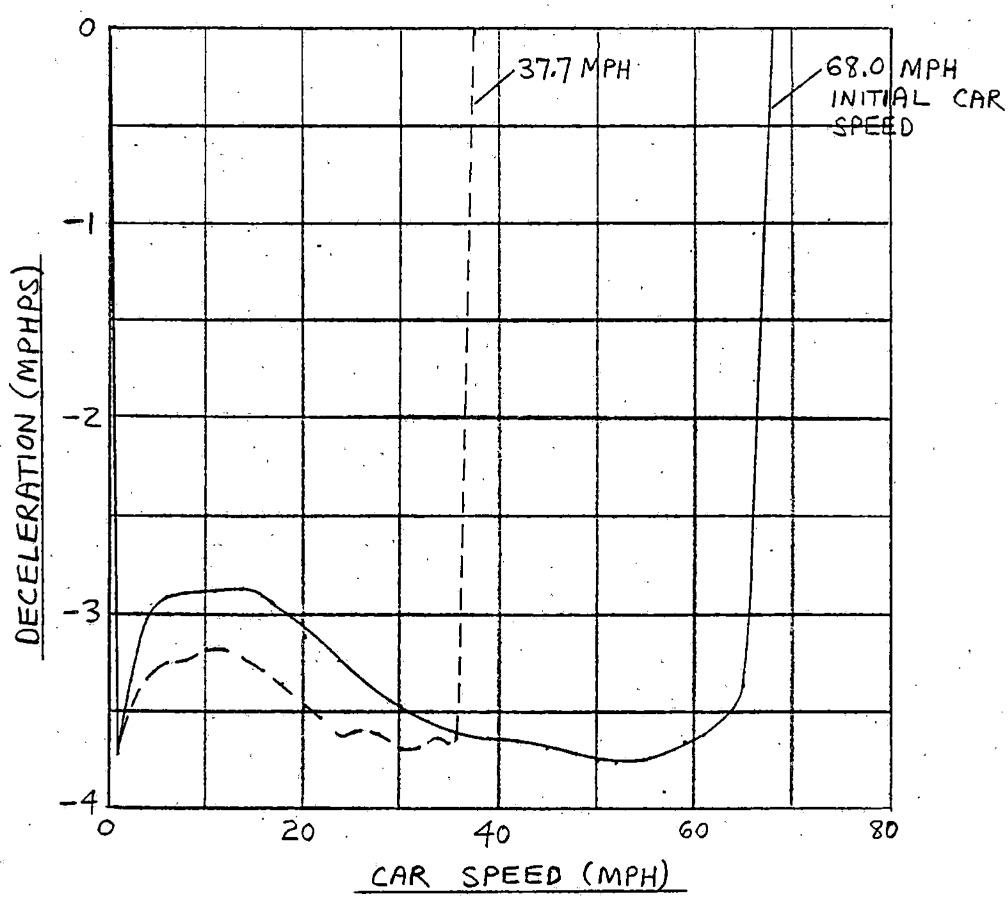


Figure 4—54. Deceleration Rate/Speed Profiles for Various Initial Car Speeds of Emergency Braking at 130,400-Lb Car Weight

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 AND DOTX-5 RECORDS:
1417 CW, 1418 CCW, 1419 CCW, 1420 CW, 1421 CCW

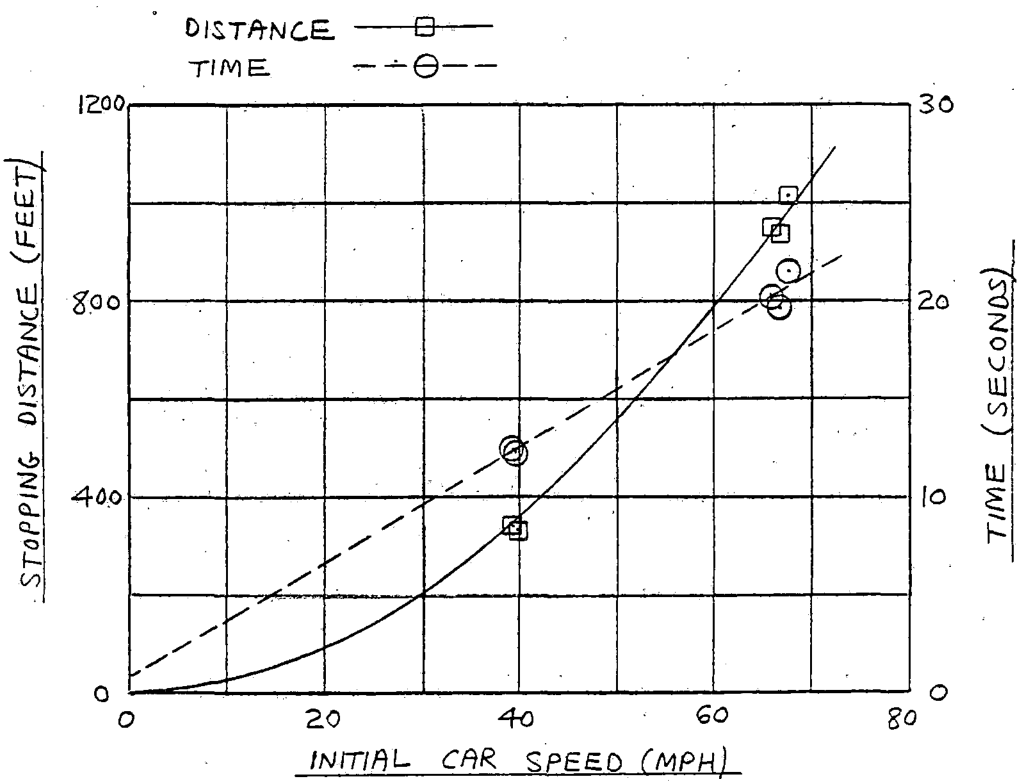


Figure 4–55. Emergency Braking Performance for a Two-Car Train at 98,000-Lb Car Weight

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-4 AND DOTX-5 RECORDS:

1417 CW - 66.0 MPH ————
1420 CW - 39.7 MPH — — — —

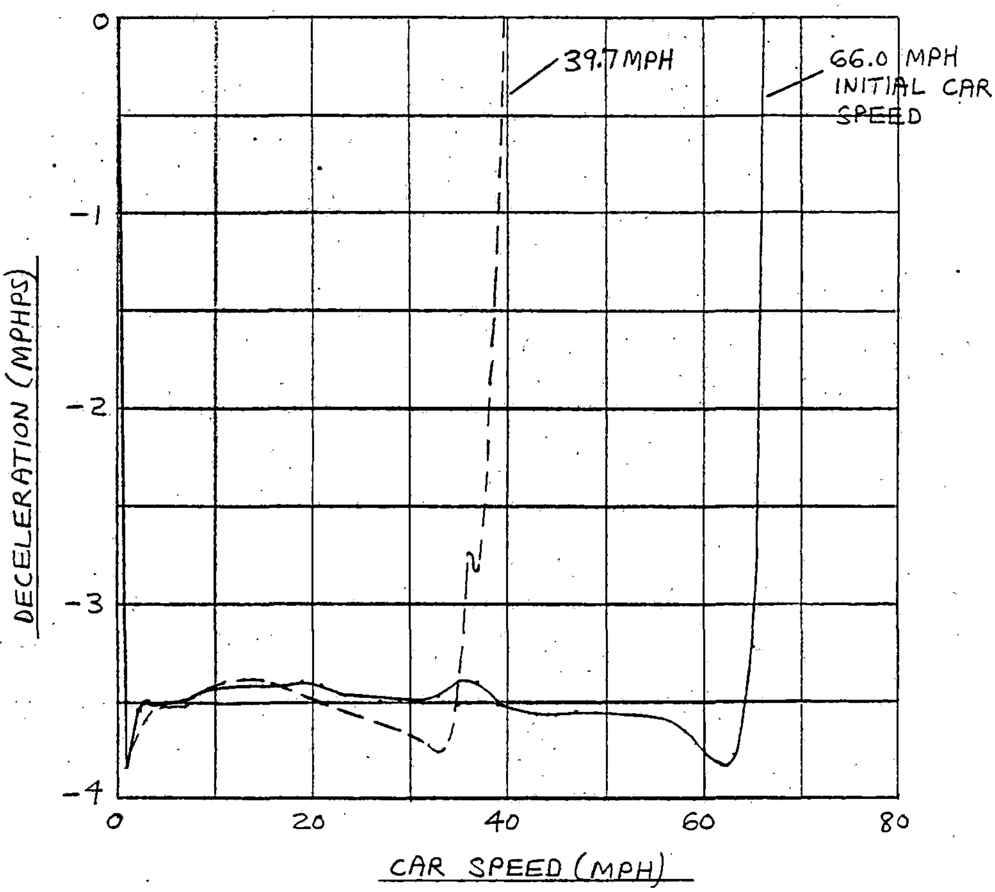


Figure 4–56. Deceleration Rate/Speed Profiles for a Two-Car Train of Emergency Braking at 98,000-Lb Car Weight

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

○ - DOTX-4
□ - DOTX-5
OPEN SYMBOLS AND SOLID LINES FOR 98,000 LB CAR WEIGHT
SOLID SYMBOLS AND DASHED LINES FOR 130,400 LB CAR WEIGHT

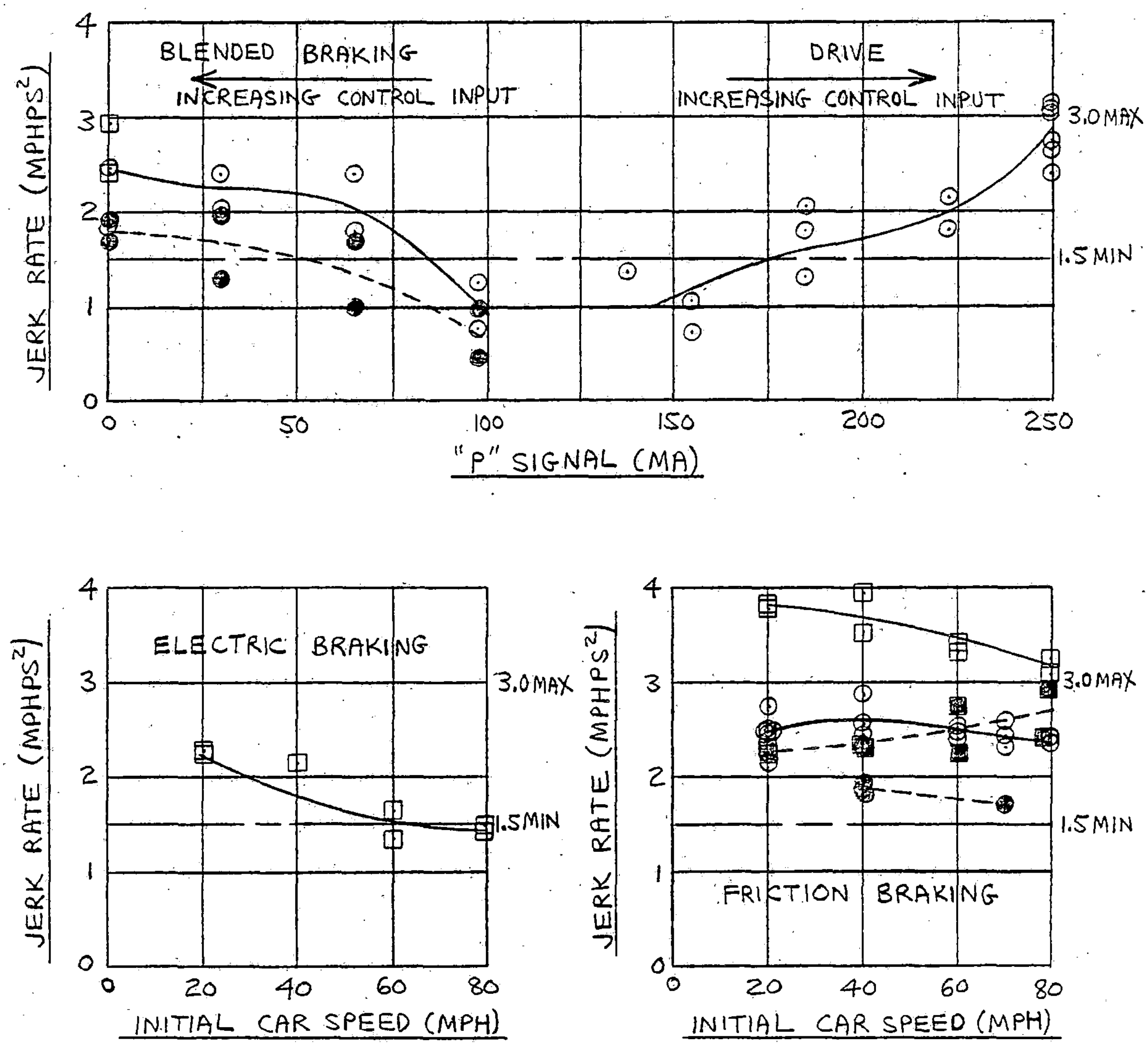


Figure 4—57. Control Response: Jerk Rate Variation With Control Input and Initial Car Speed

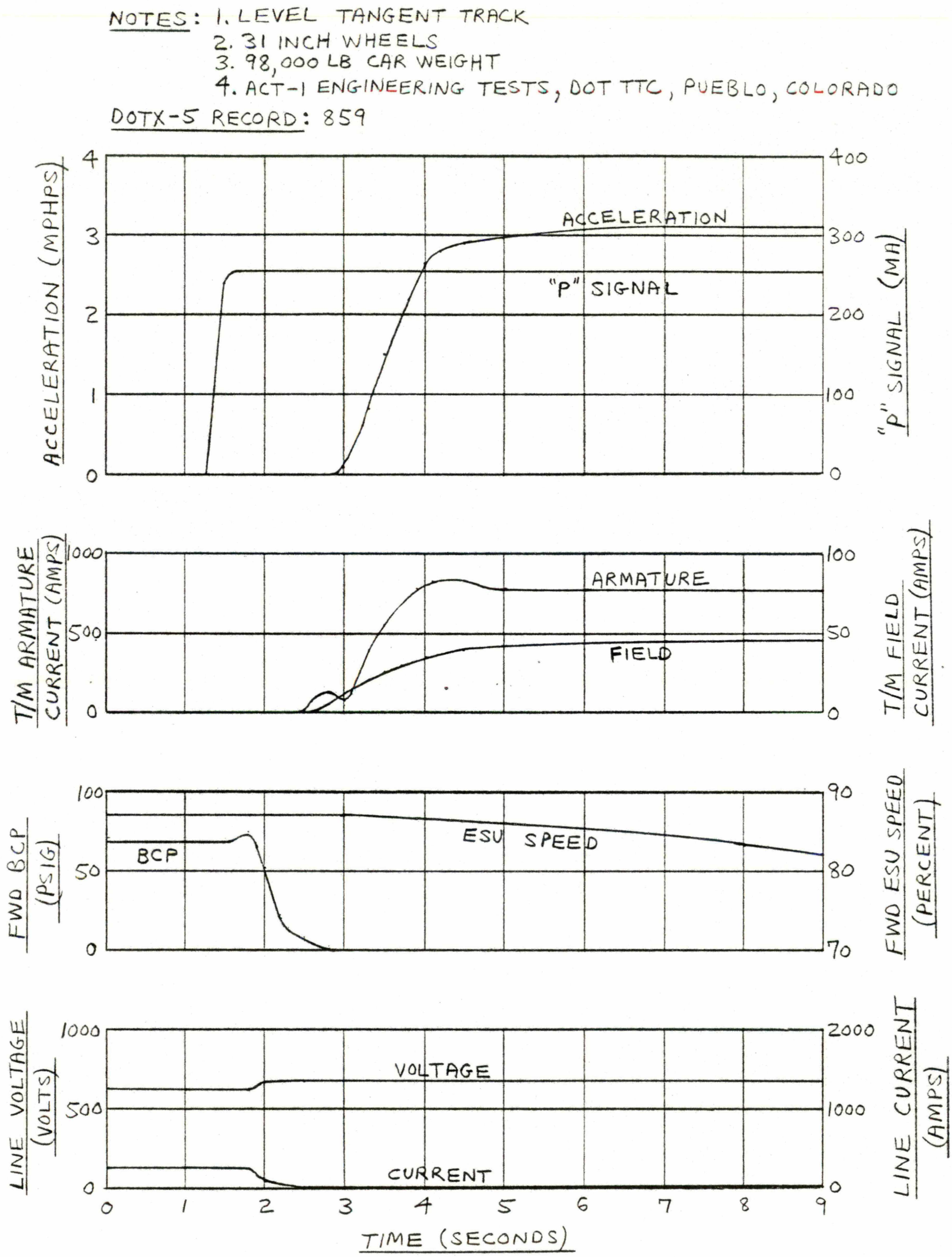


Figure 4–58. Control Response: Brake to Drive Mode Transition at Startup

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 98,000 LB CAR WEIGHT
4. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOTX-5 RECORD: 861

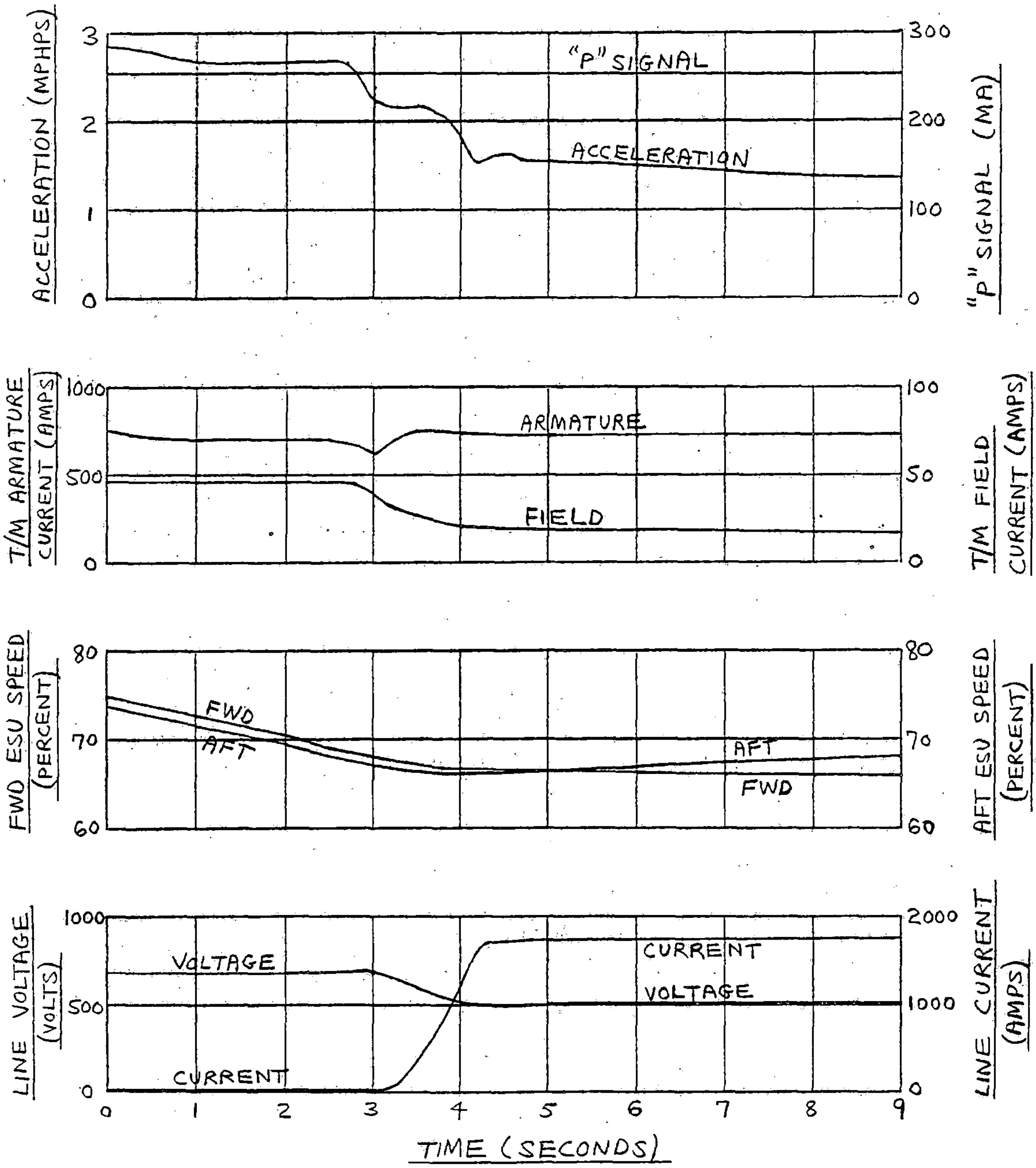


Figure 4—59. Control Response: Parallel Off-Line to Parallel On-Line Mode Transition

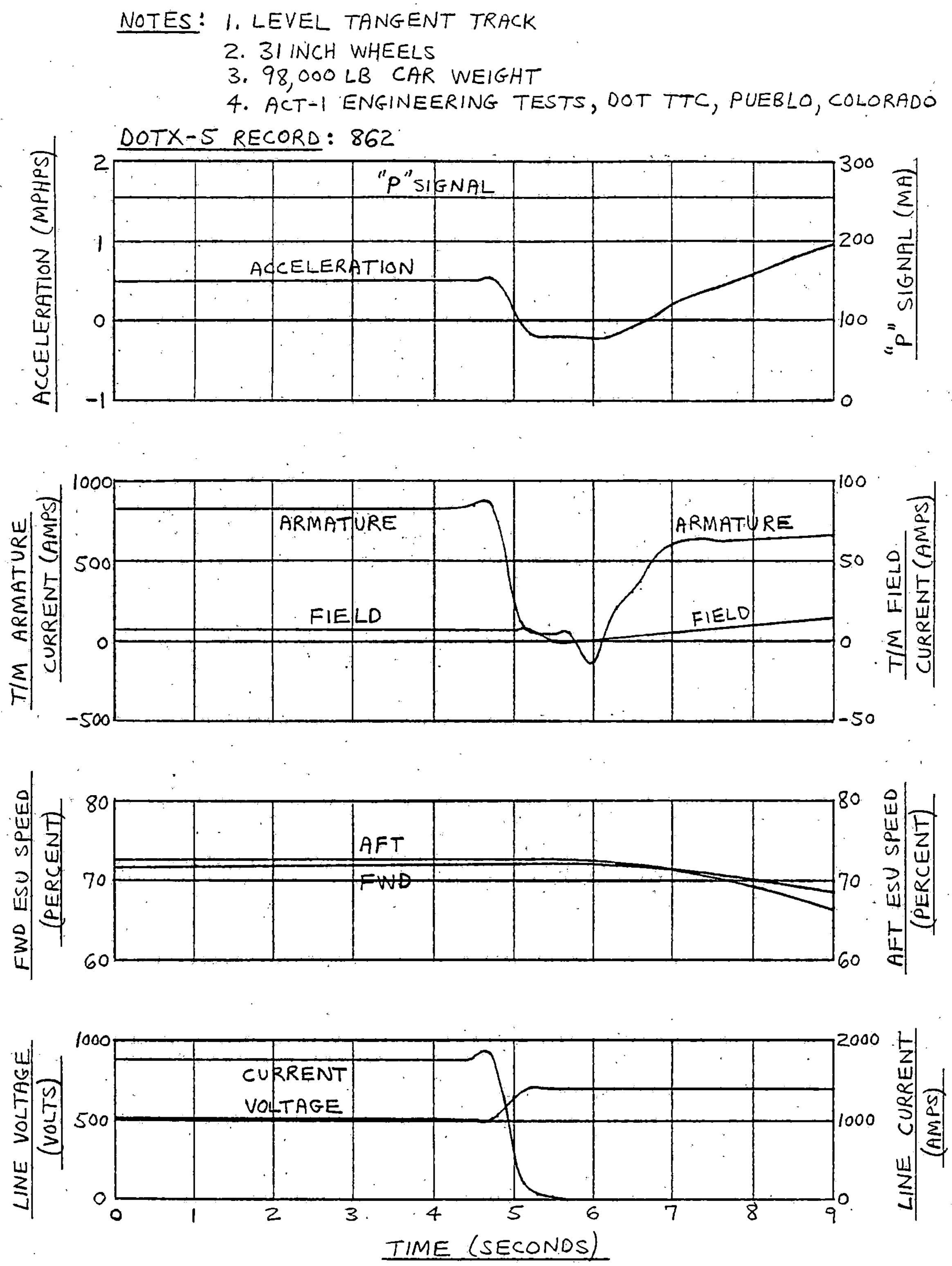


Figure 4–60. Control Response: Series to Parallel Off-Line Mode Transition

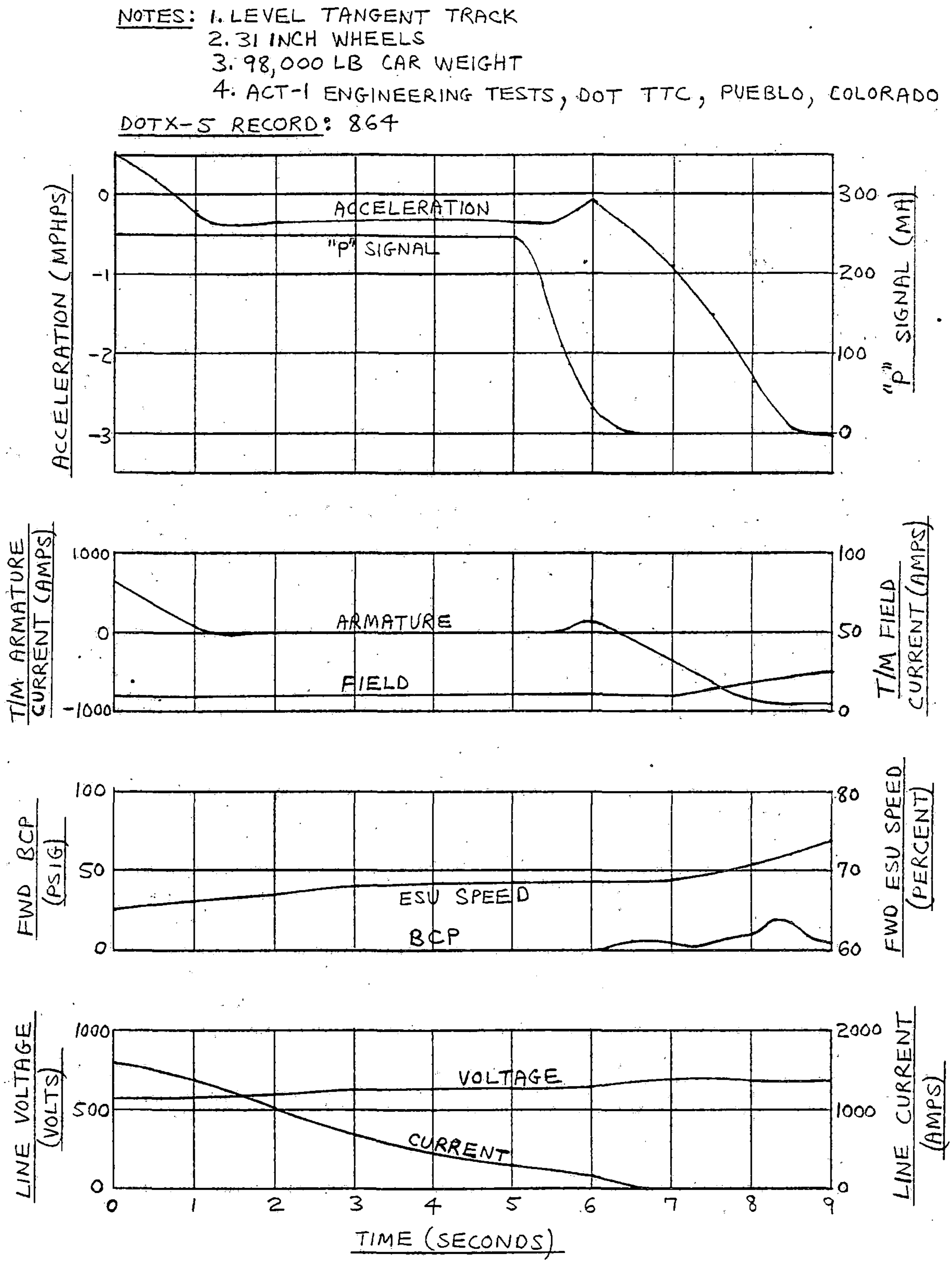


Figure 4–61. Control Response: Parallel On-Line to Brake Mode Transition

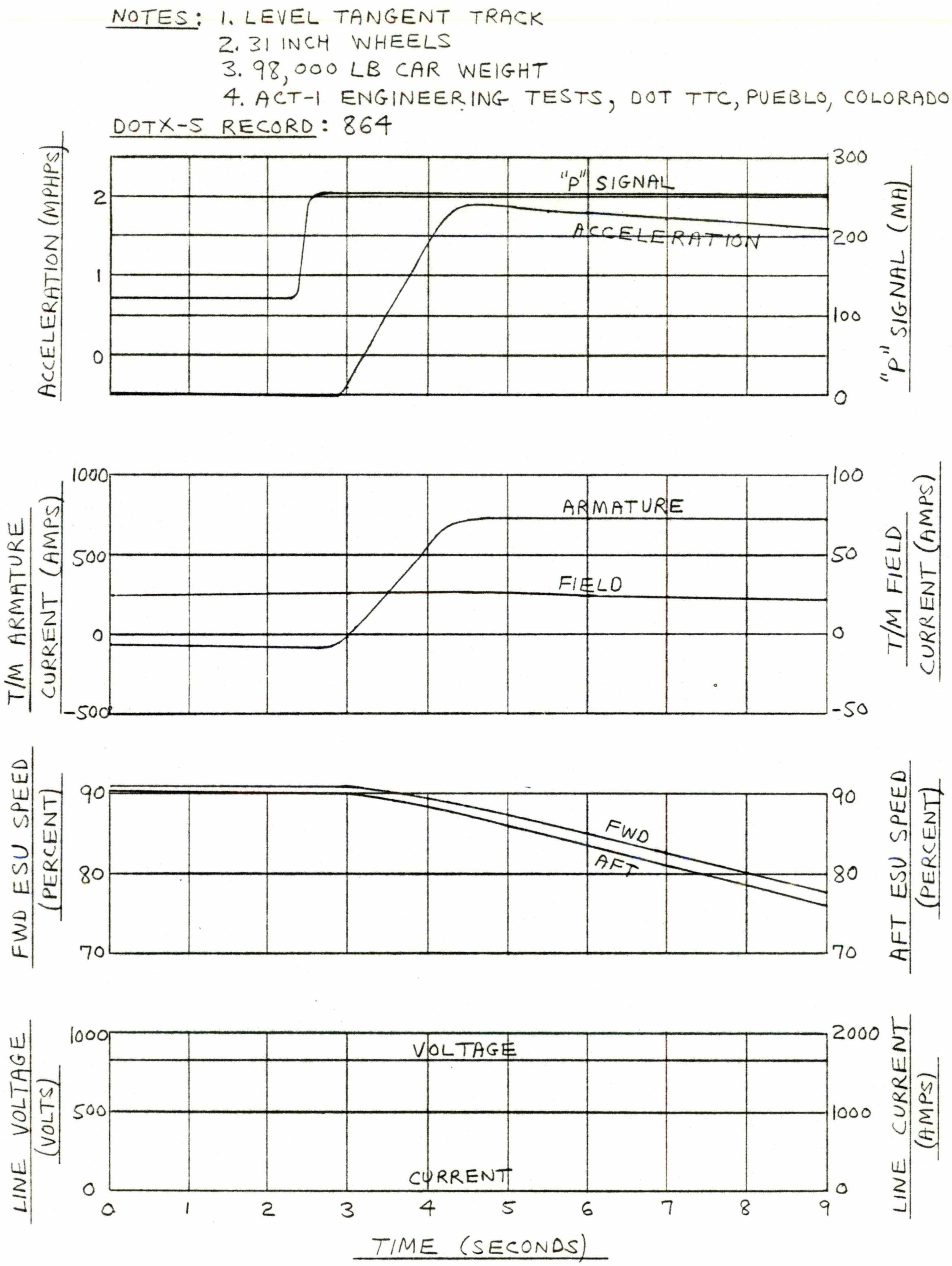


Figure 4–62. Control Response: Coast to Drive Mode Transition Above Base Speed

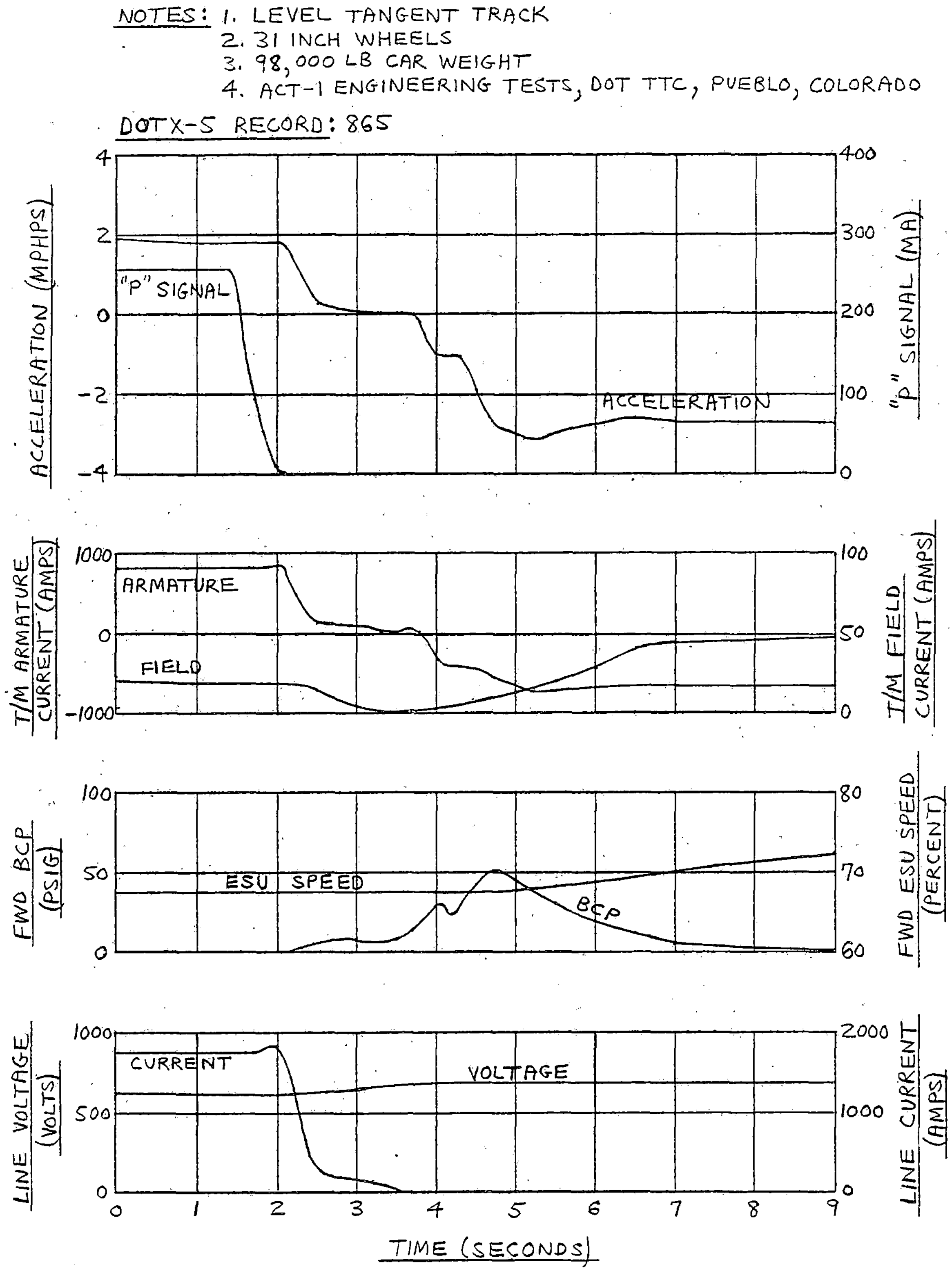


Figure 4—63. Control Response: Series to Brake Mode Transition

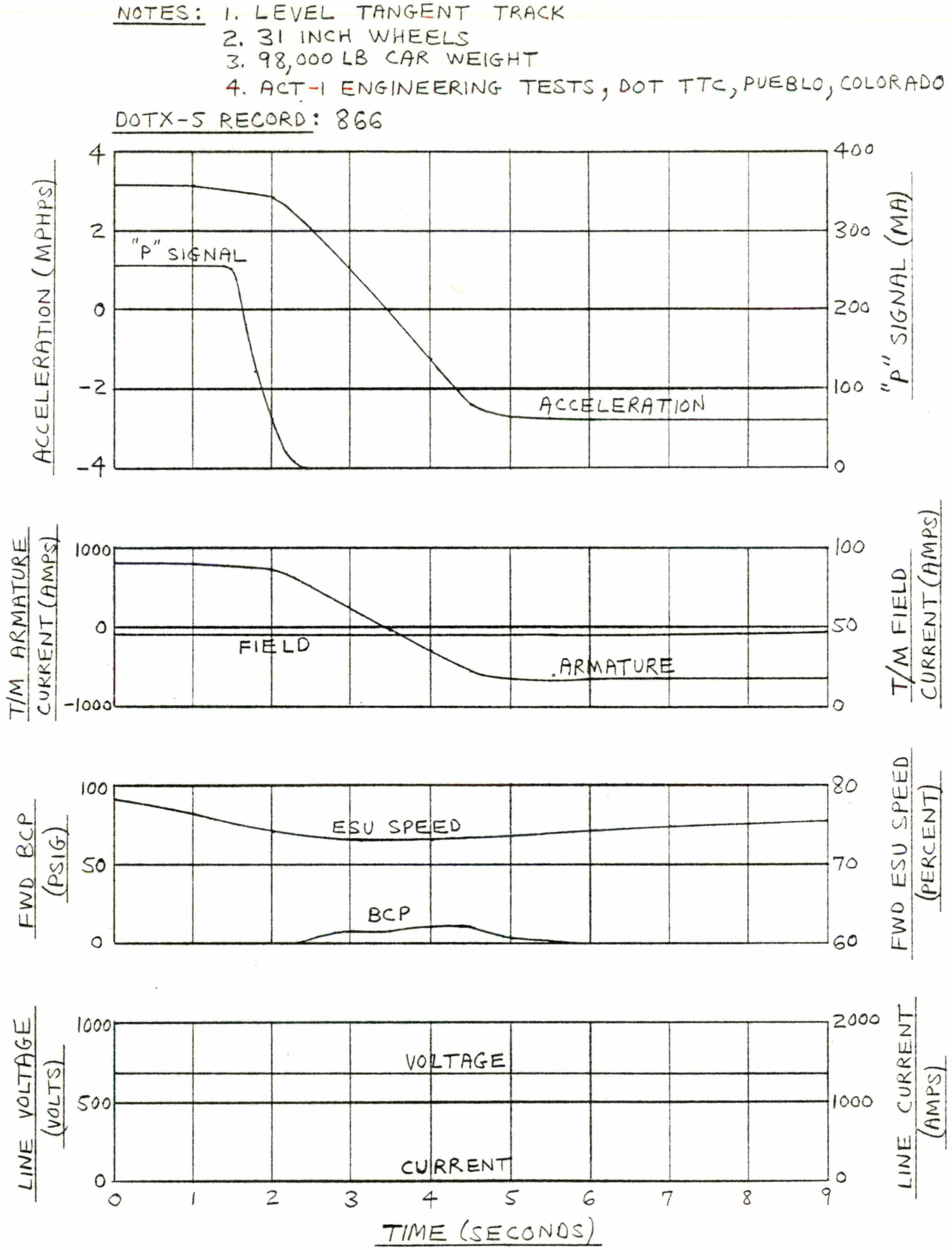


Figure 4–64. Control Response: Parallel Off-Line to Brake Mode Transition

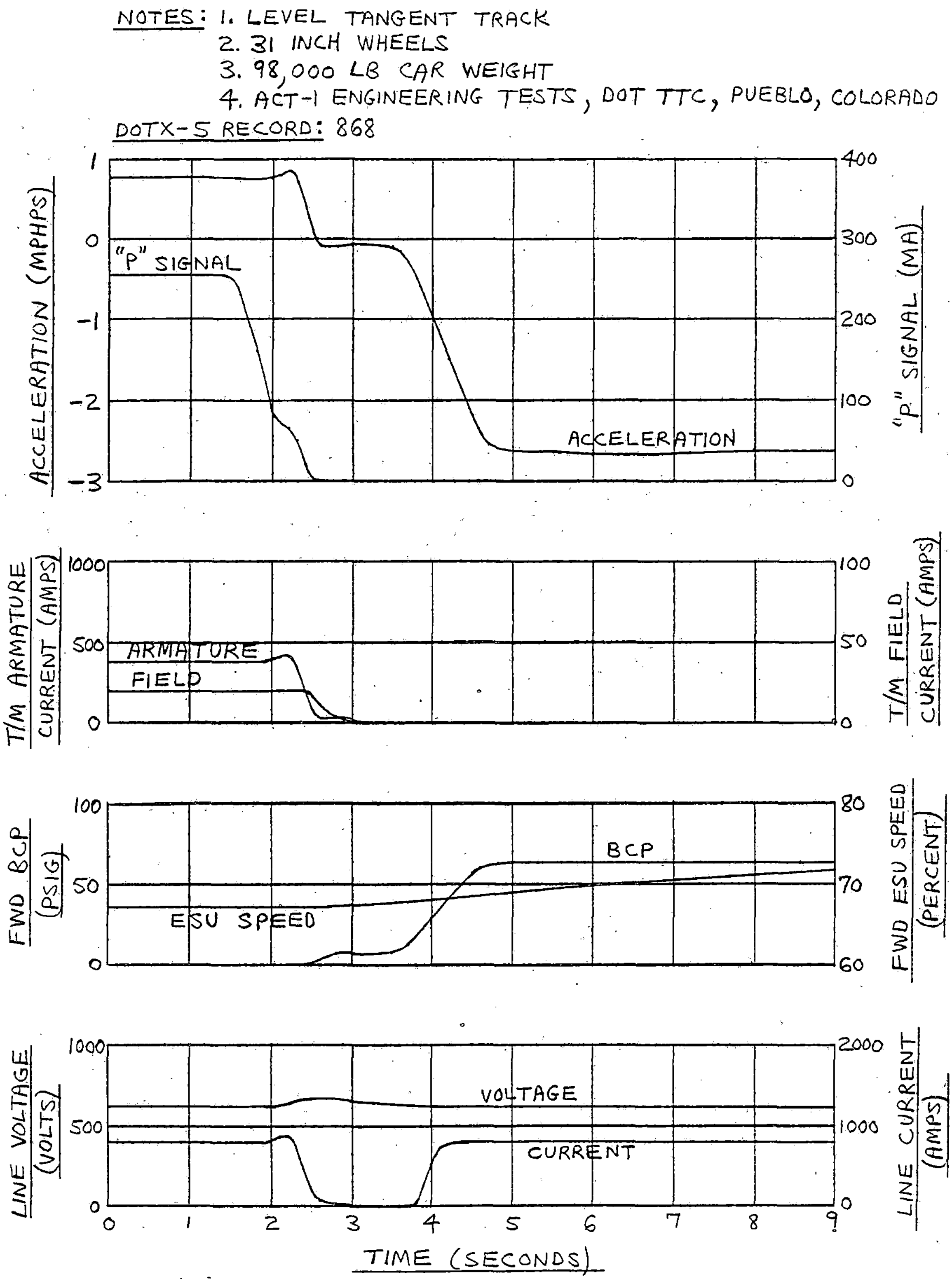


Figure 4–65. Control Response: Series to Friction Brake Mode Transition

NOTES: 1. LEVEL TANGENT TRACK
2. 31 INCH WHEELS
3. 98,000 LB AW1 CAR WEIGHT
4. ACT-1 ENGINEERING TESTS, DOT TTC, PUEBLO, COLORADO

DOT X-4 RECORDS:

○ 1356
□ 1357

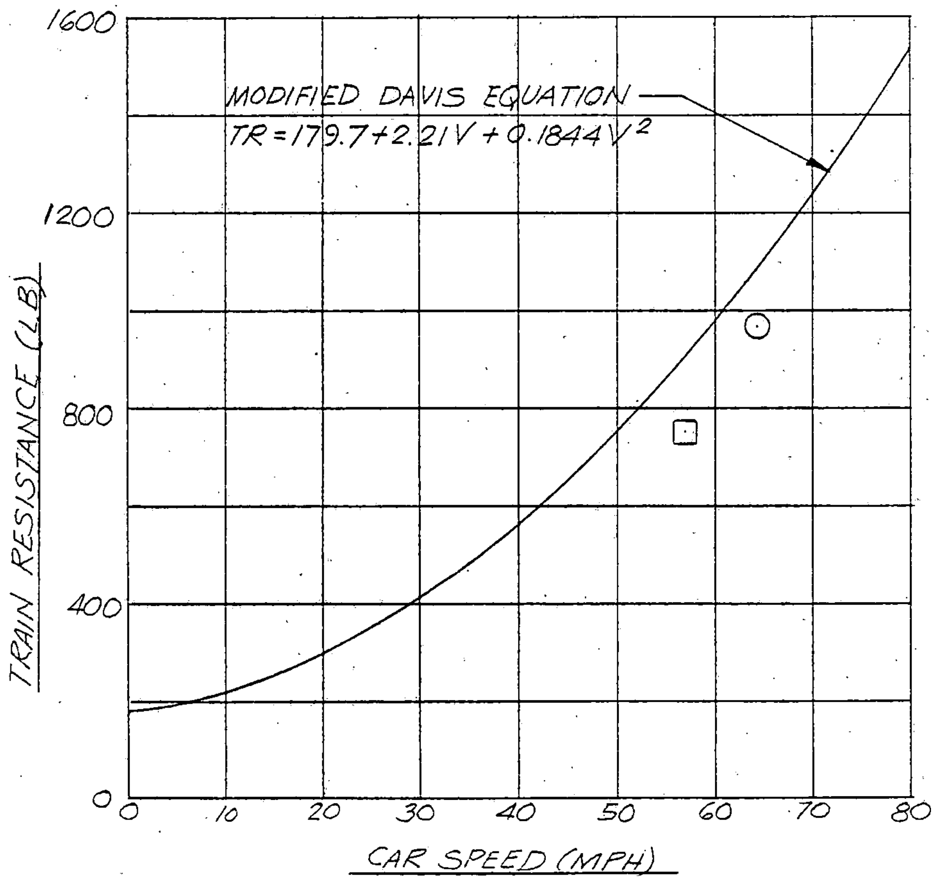


Figure 4–66. Train Resistance

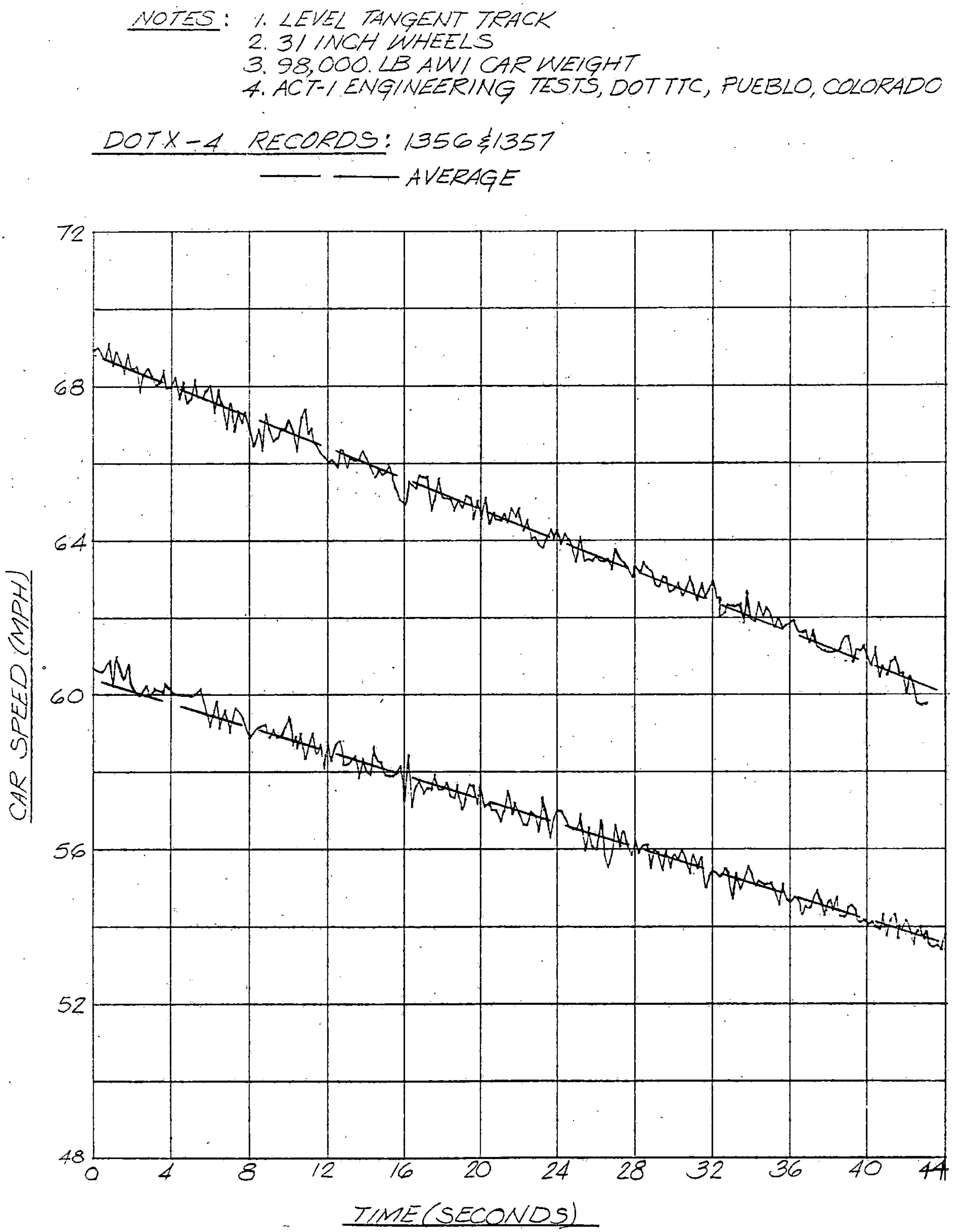


Figure 4–67. Drift Performance

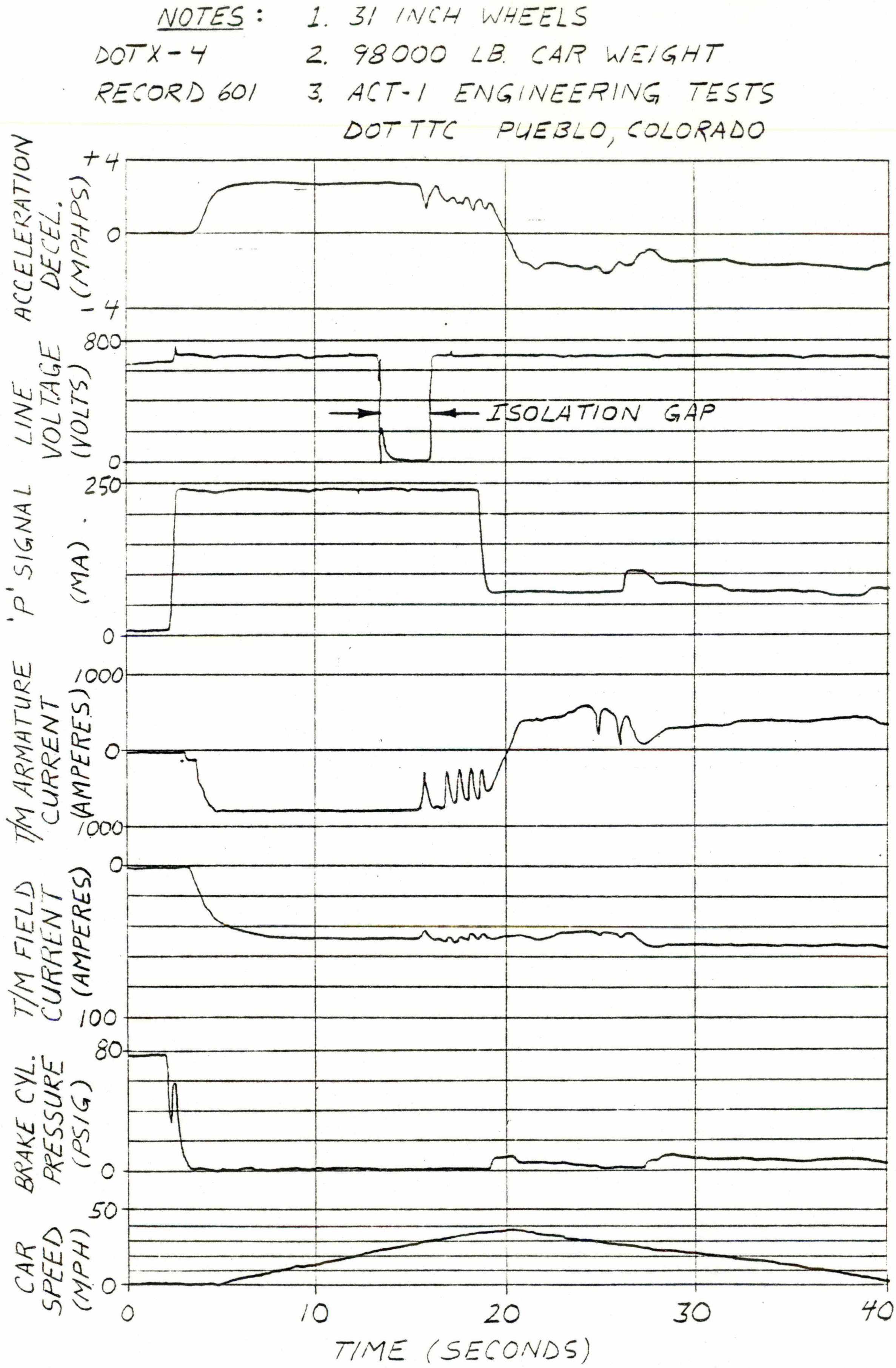


Figure 4–68. Power Isolation Gap Performance: Parallel Off-Line, No Third Rail Enable, High Acceleration Rate

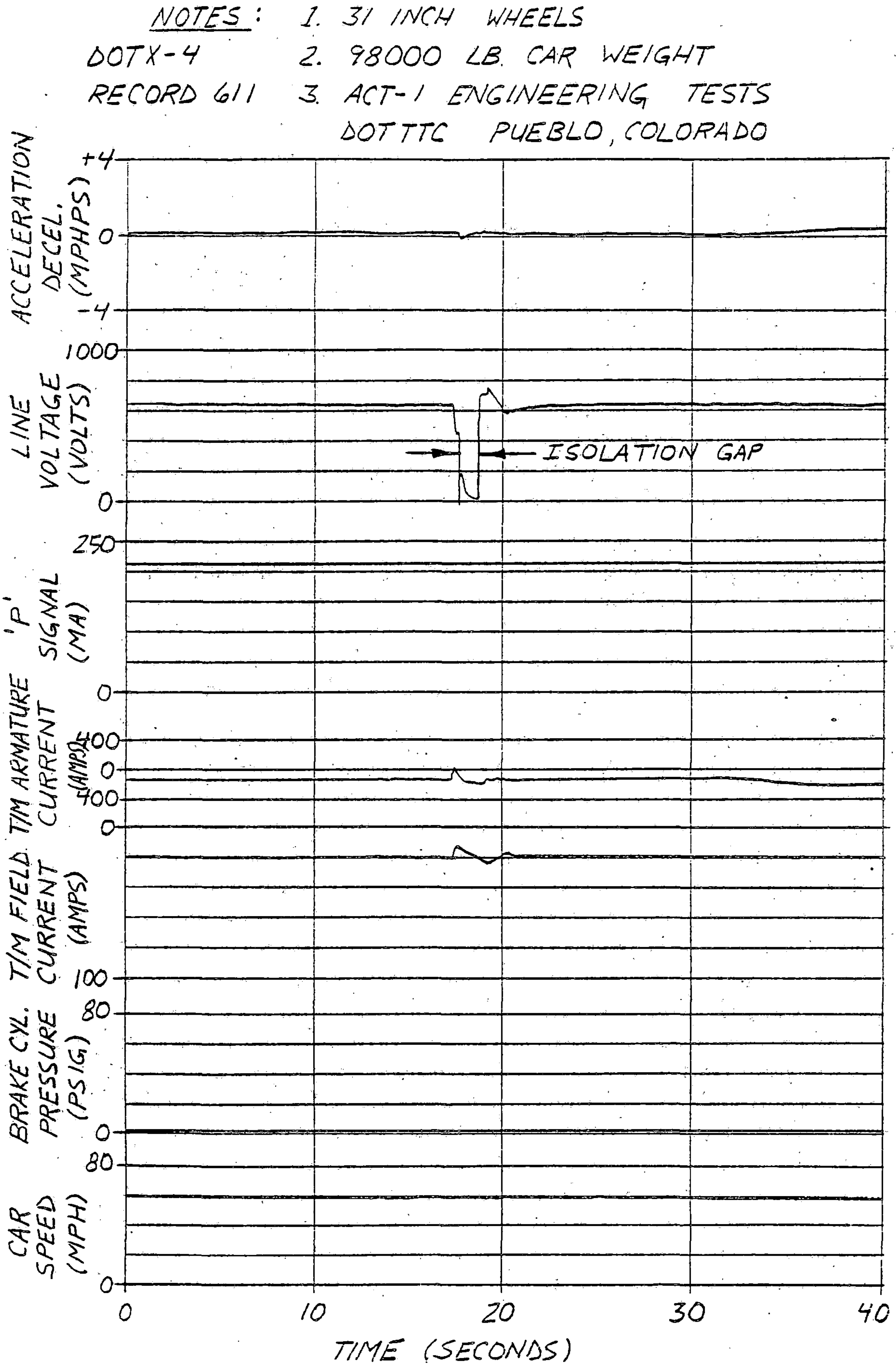


Figure 4–69. Power Isolation Gap Performance: Parallel On-Line, No Third Rail Enable, Low Acceleration Rate

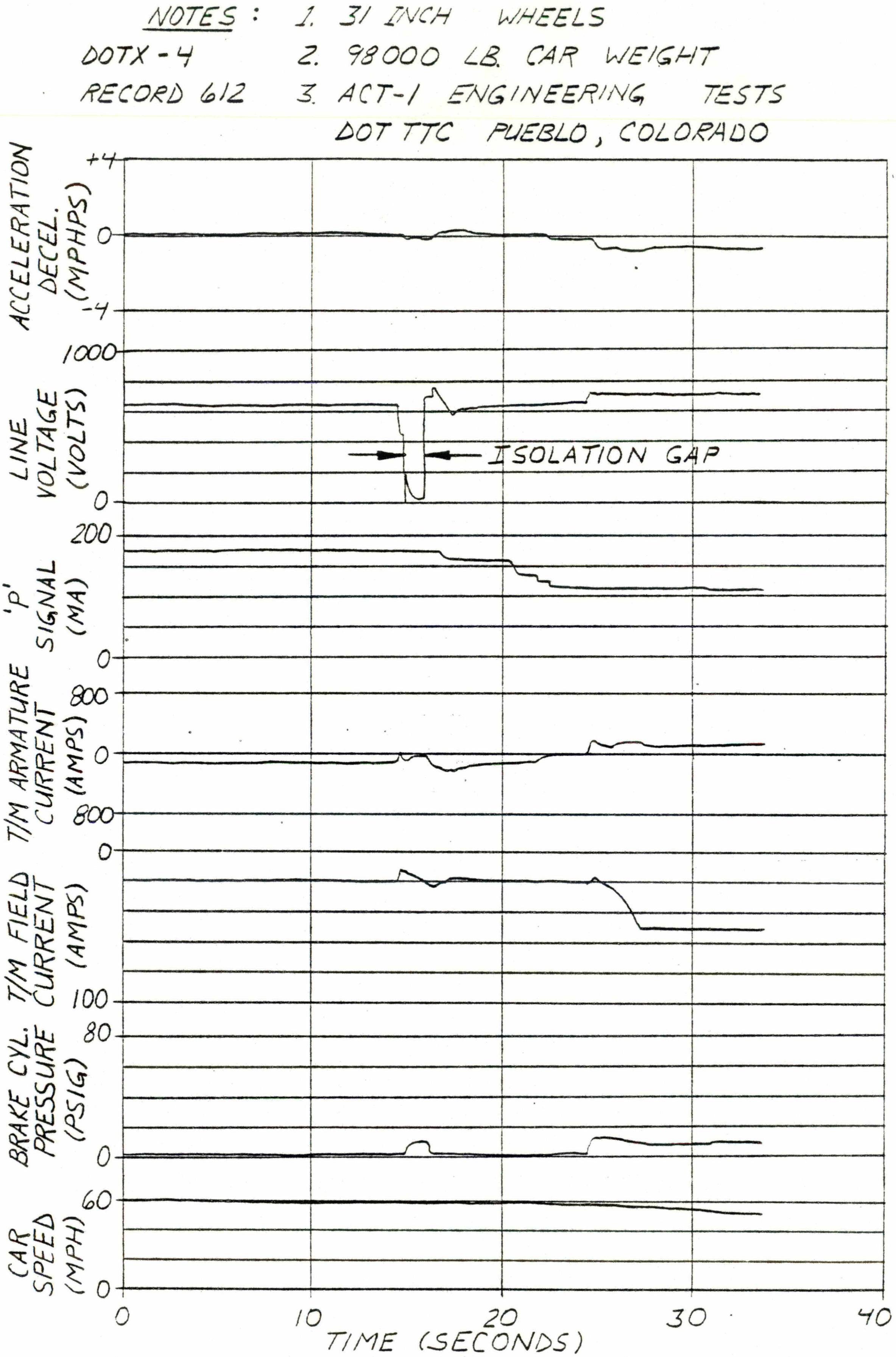


Figure 4—70. Power Isolation Gap Performance: Parallel On-Line, Third Rail Enable, Low Acceleration Rate

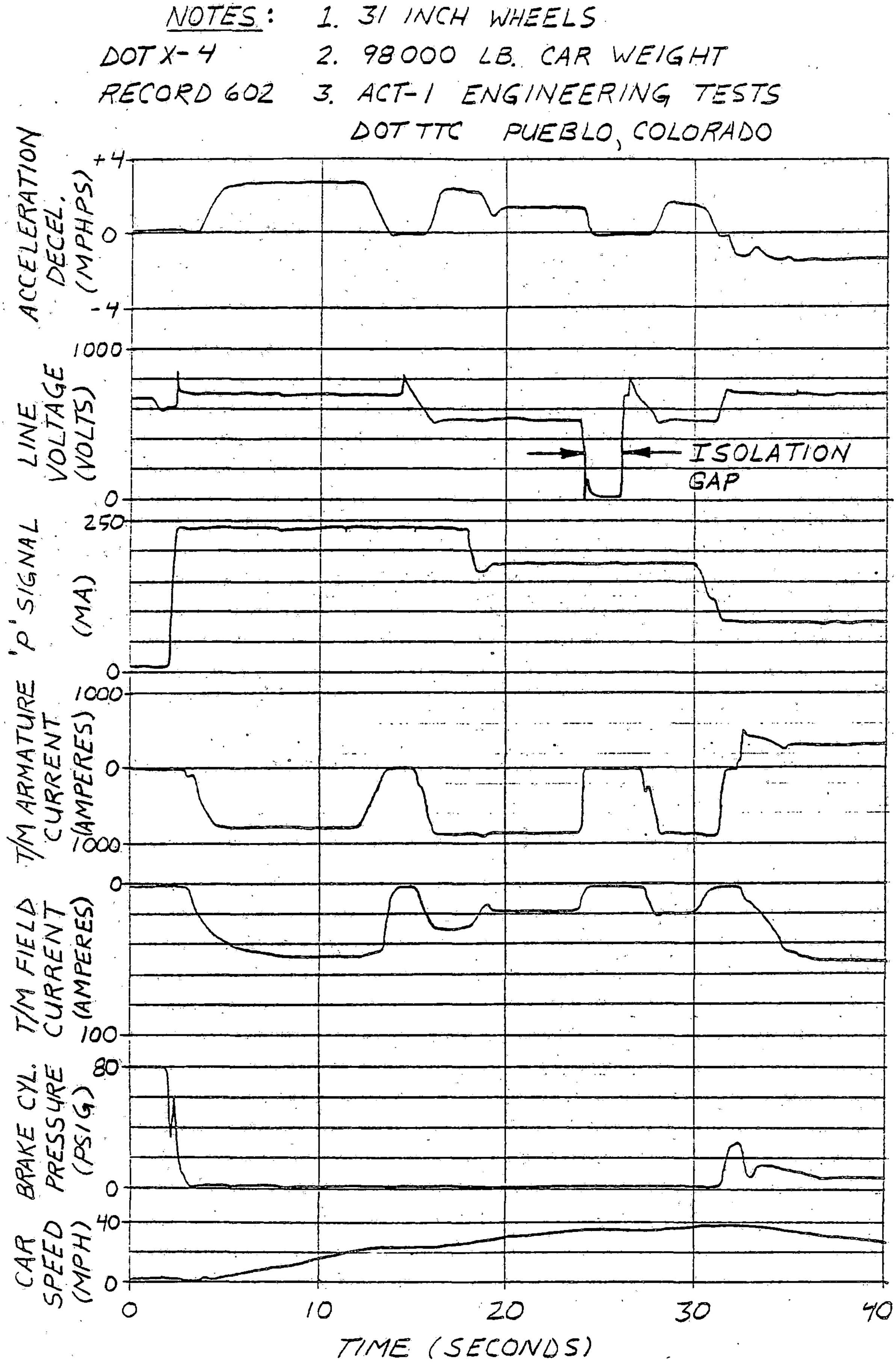


Figure 4–71. Power Isolation Gap Performance: Series Mode, No Third Rail Enable, Low Acceleration Rate

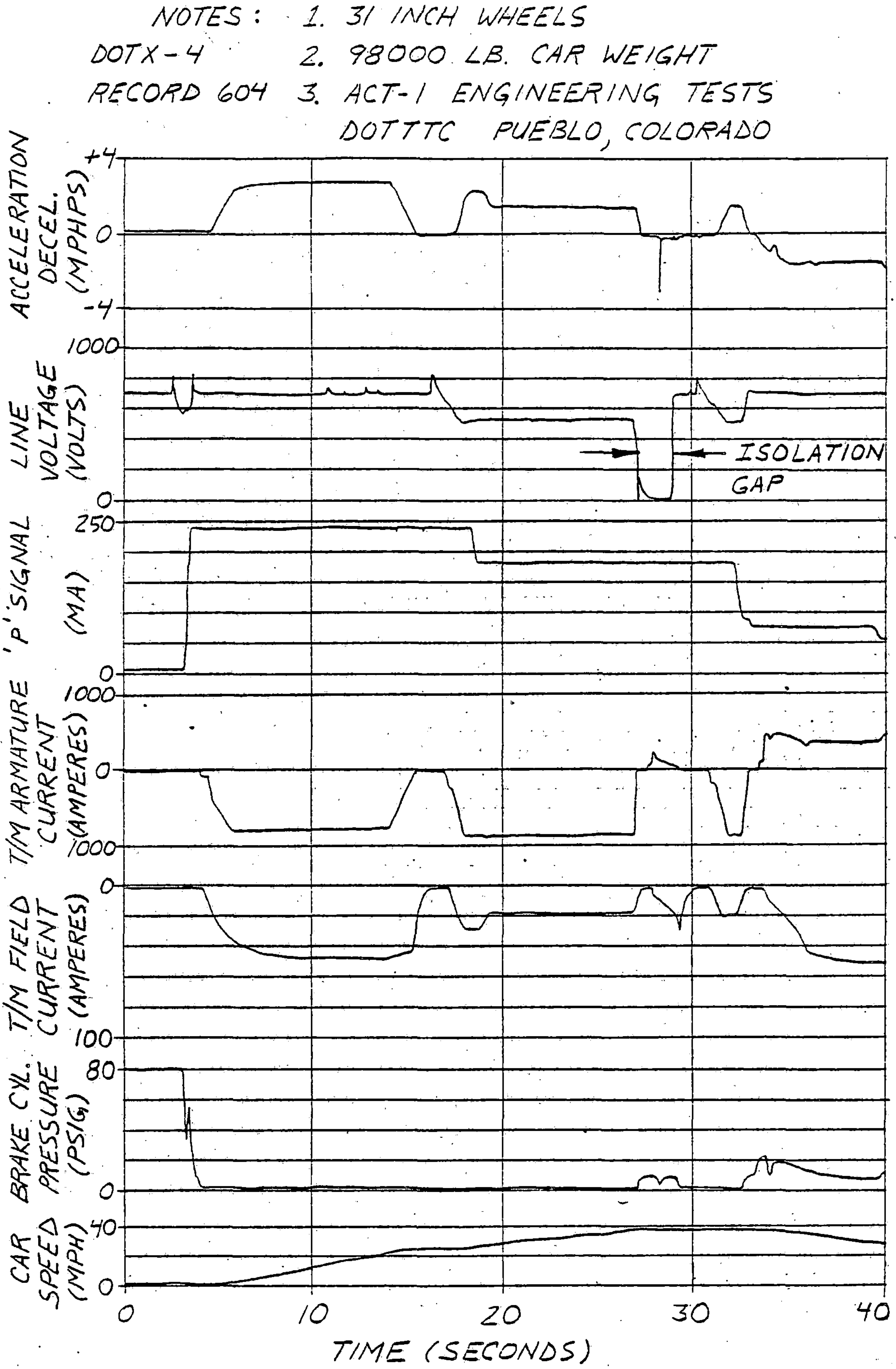


Figure 4—72. Power Isolation Gap Performance: Series Mode With Third Rail Enable, Low Acceleration Rate

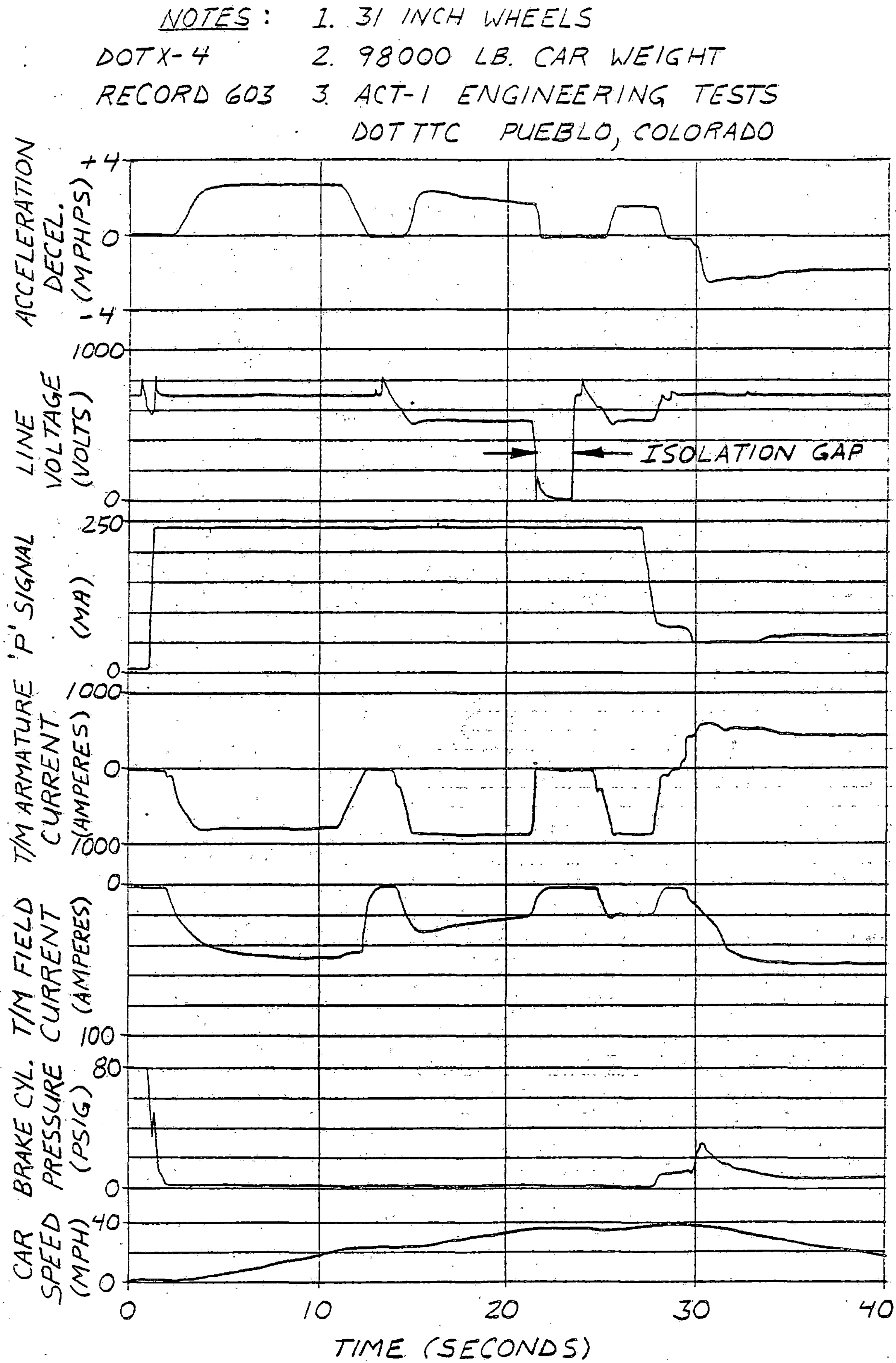


Figure 4–73. Power Isolation Gap Performance: Series Mode, No Third Rail Enable, High Acceleration Rate

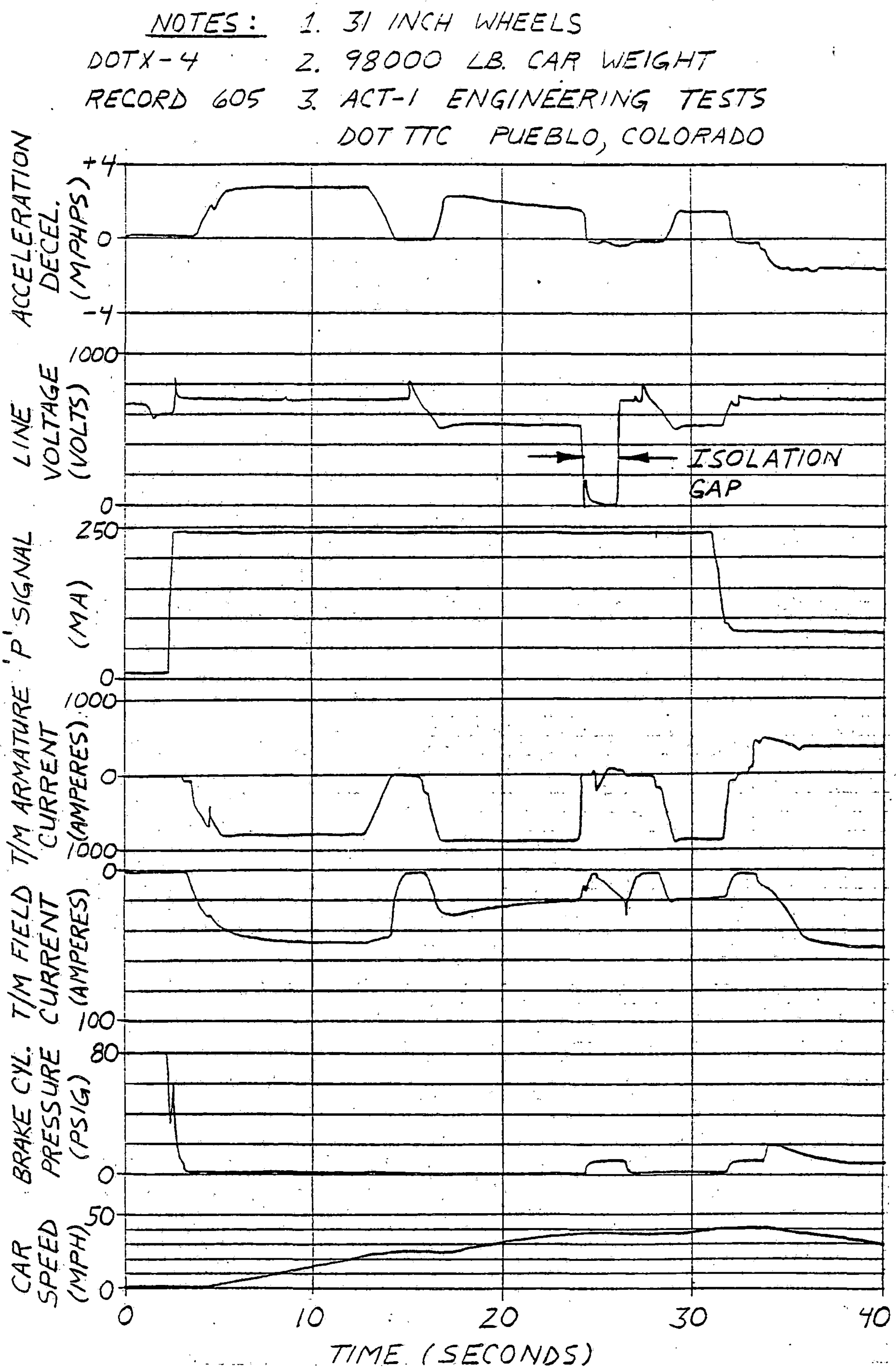


Figure 4–74. Power Isolation Gap Performance: Series Mode With Third Rail Enable, High Acceleration Rate

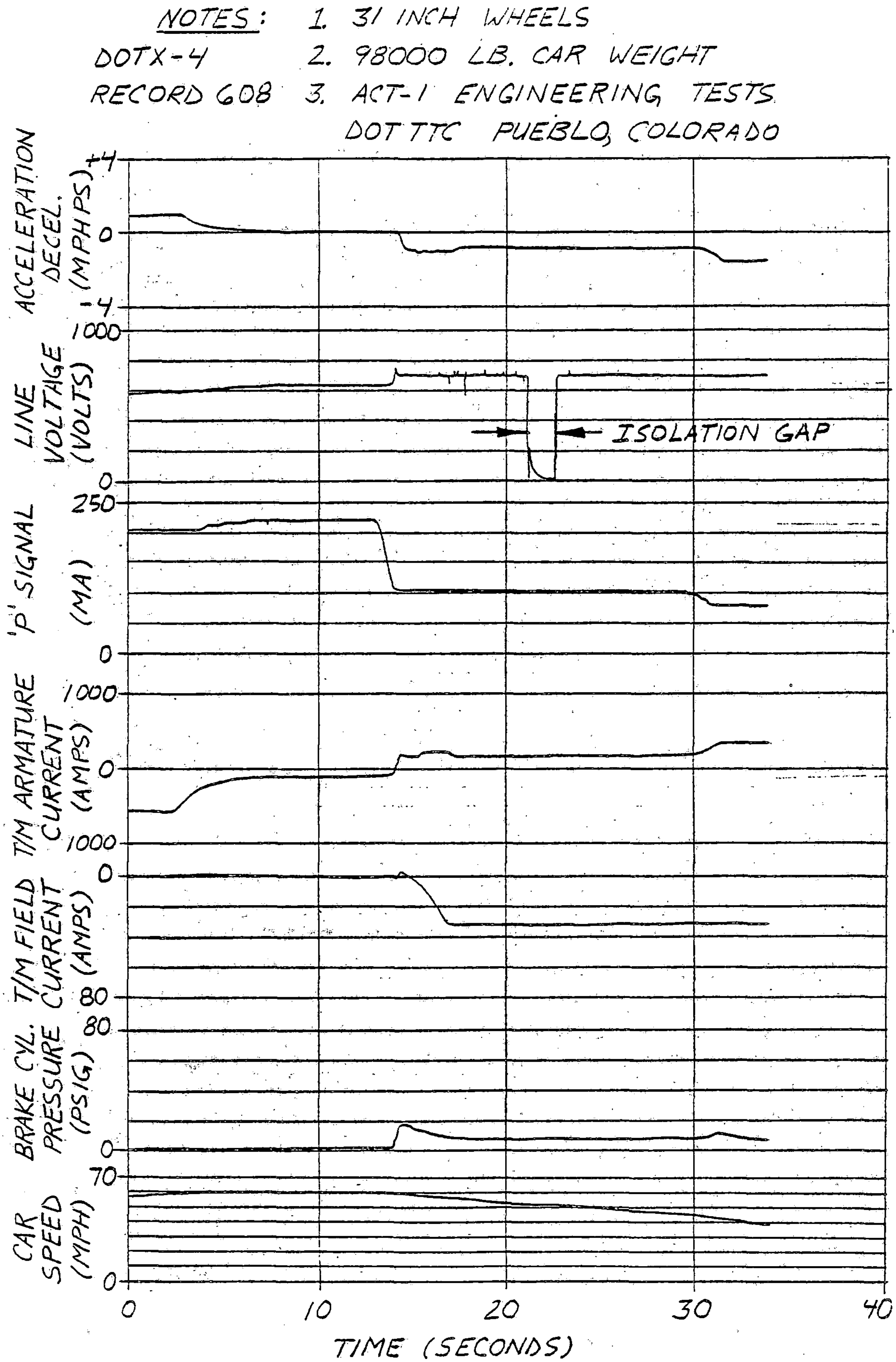


Figure 4–75. Power Isolation Gap Performance: Braking, No Third Rail Enable, Low Brake Rate

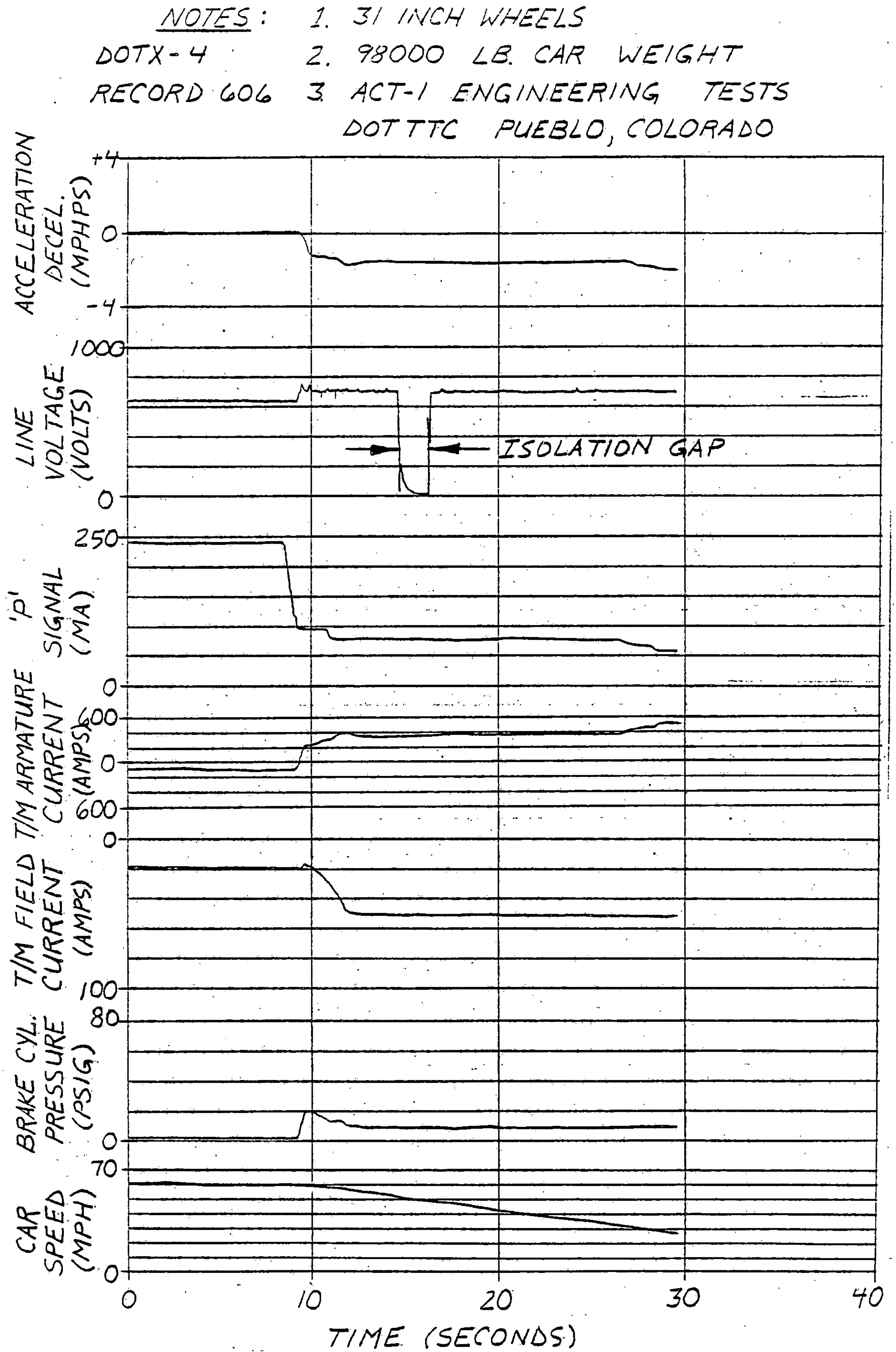


Figure 4–76. Power Isolation Gap Performance: Braking With Third Rail Enable, Low Brake Rate

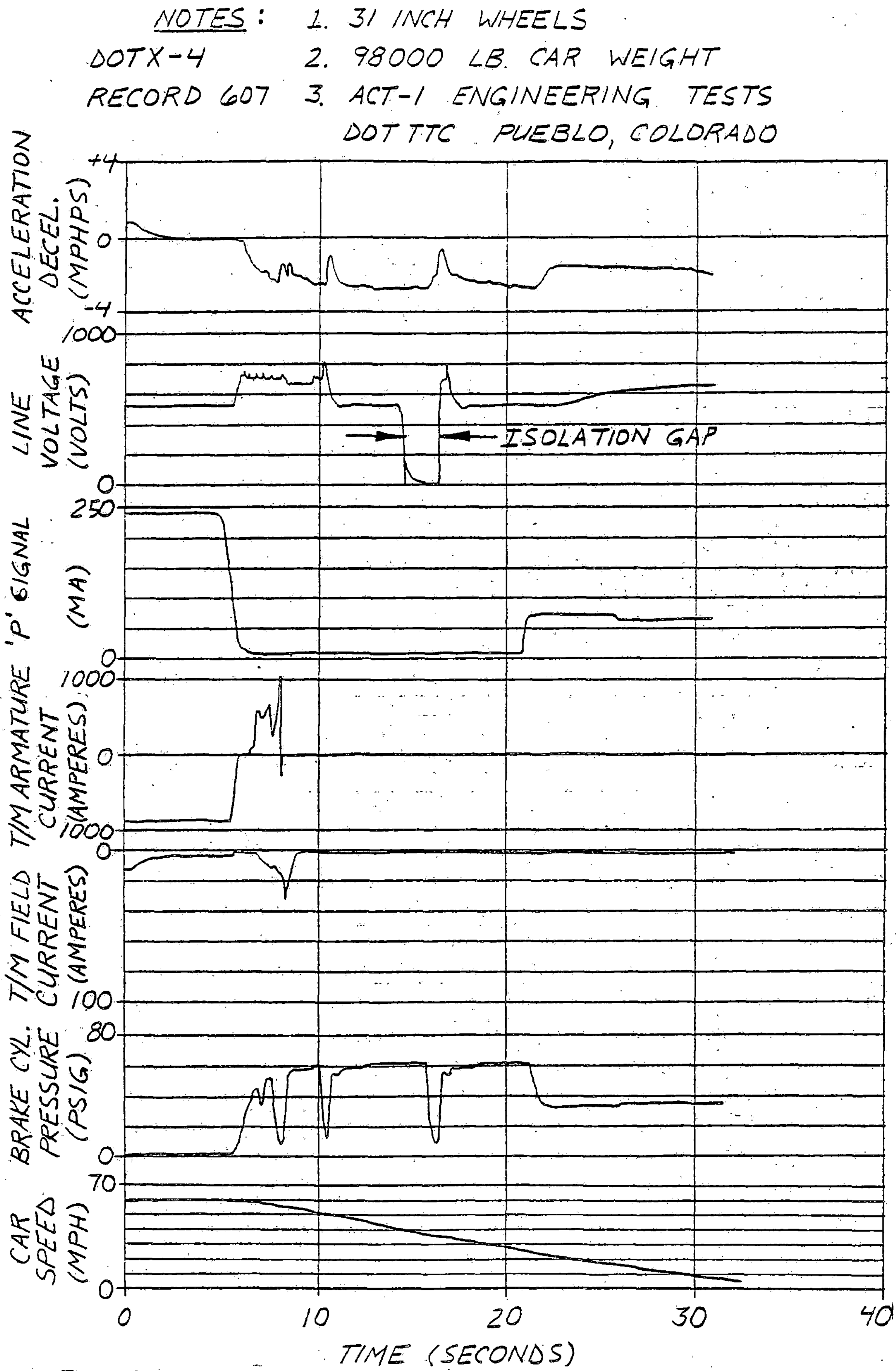


Figure 4–77. Power Isolation Gap Performance: Braking With Third Rail Enable, High Brake Rate

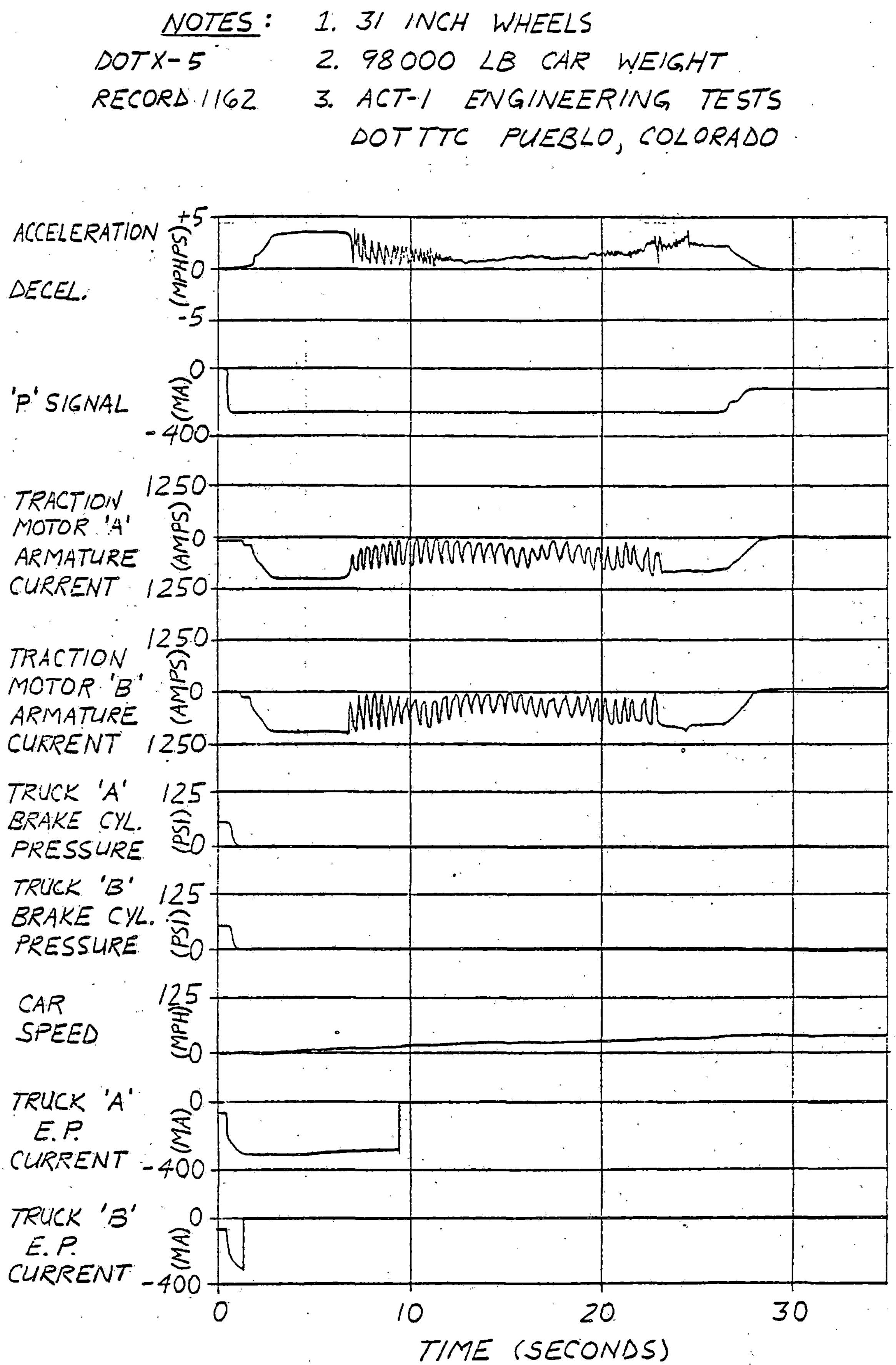


Figure 4—78. Slip-Spin Acceleration

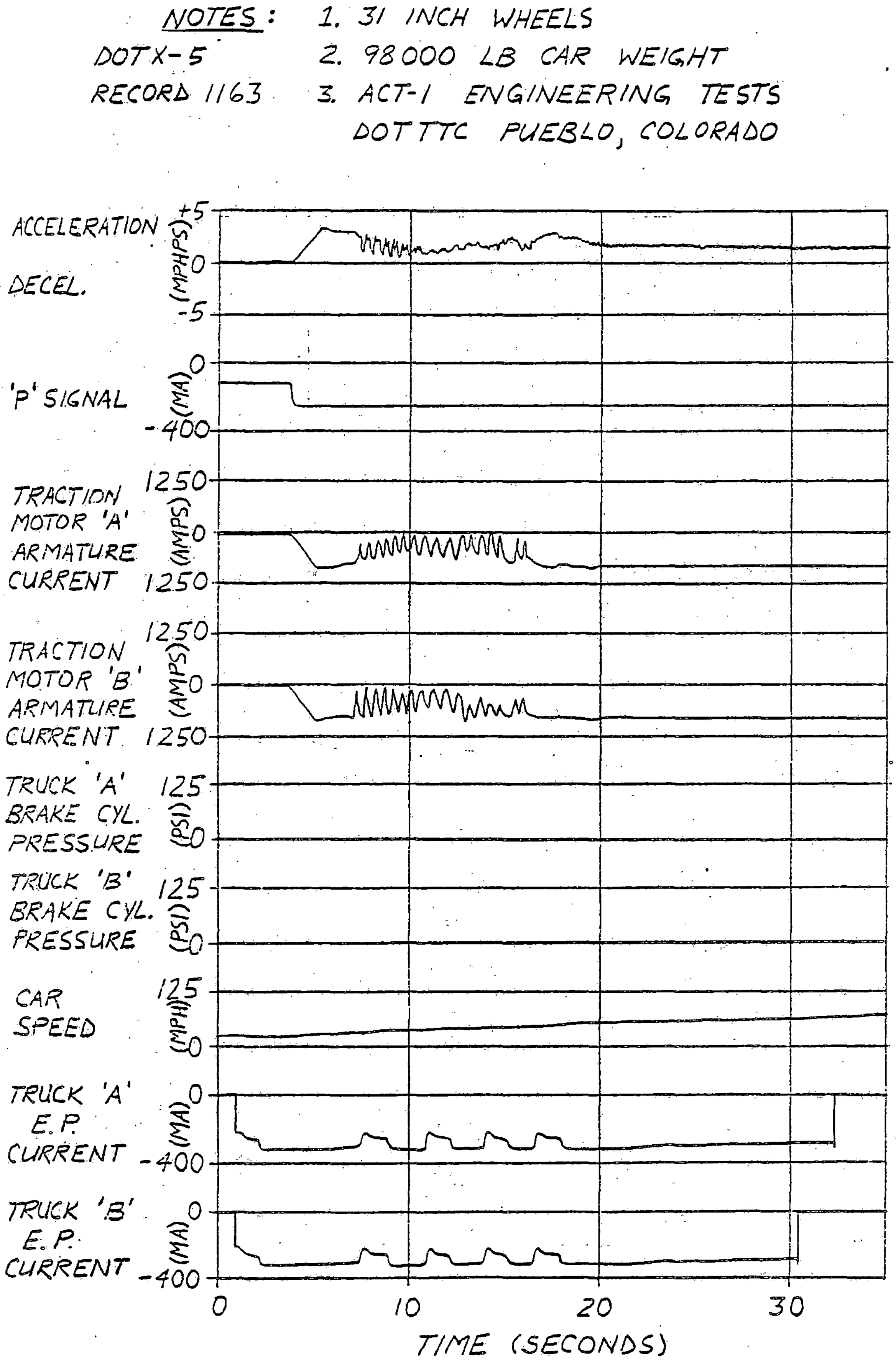


Figure 4—79. Slip-Spin Acceleration

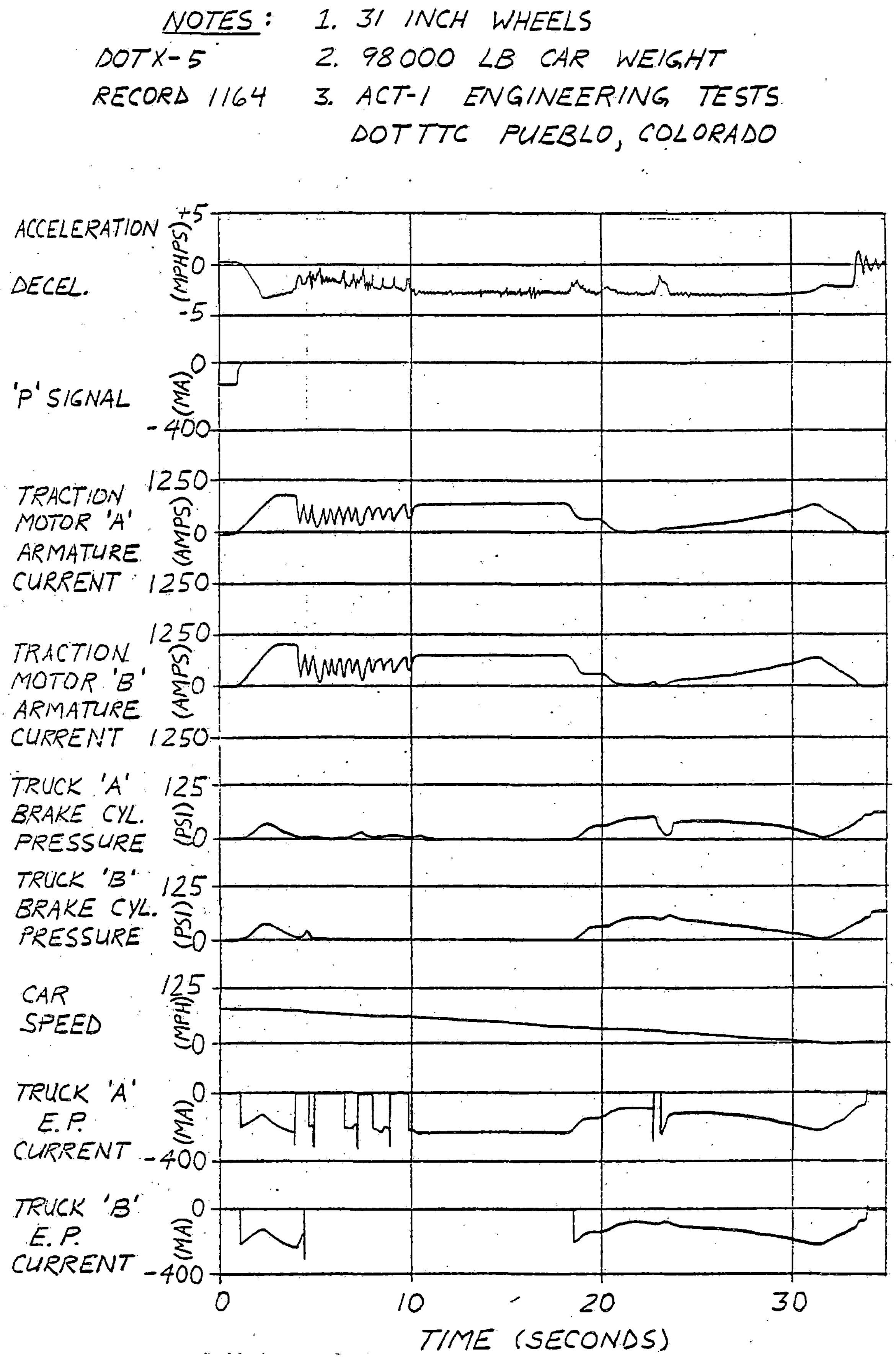


Figure 4—80. Slip-Slide Deceleration in Blended Braking

NOTES: 1. 31 INCH WHEELS
DOTX-5 2. 98000 LB CAR WEIGHT
RECORD 1165 3. ACT-1 ENGINEERING TESTS
DOTTTC PUEBLO, COLORADO

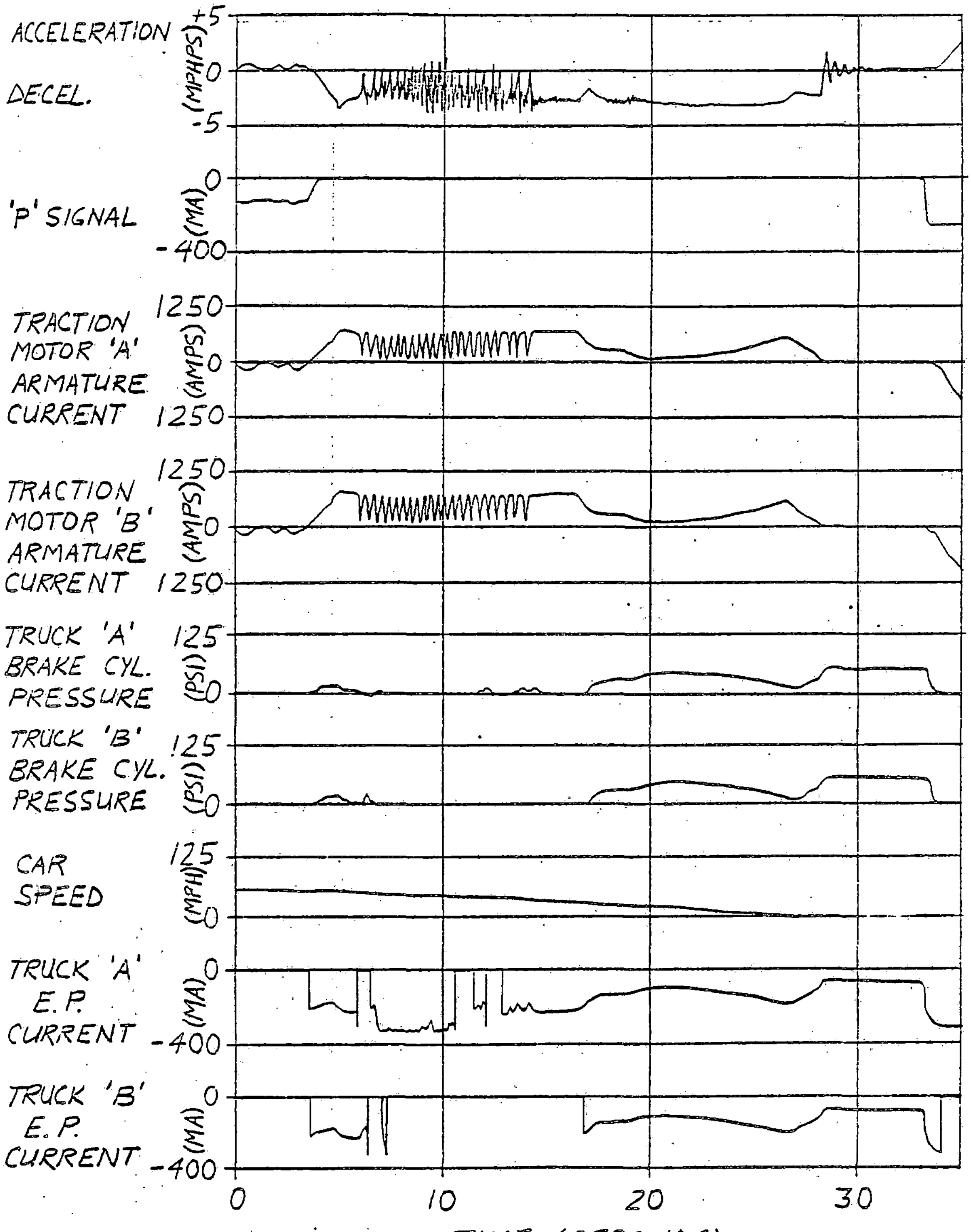


Figure 4–81. Slip-Slide Deceleration in Blended Braking

NOTES: 1. 31 INCH WHEELS
DOTX-5 2. 98000 LB CAR WEIGHT
RECORD 1168 3. ACT-1 ENGINEERING TESTS
DOT TTC PUEBLO, COLORADO

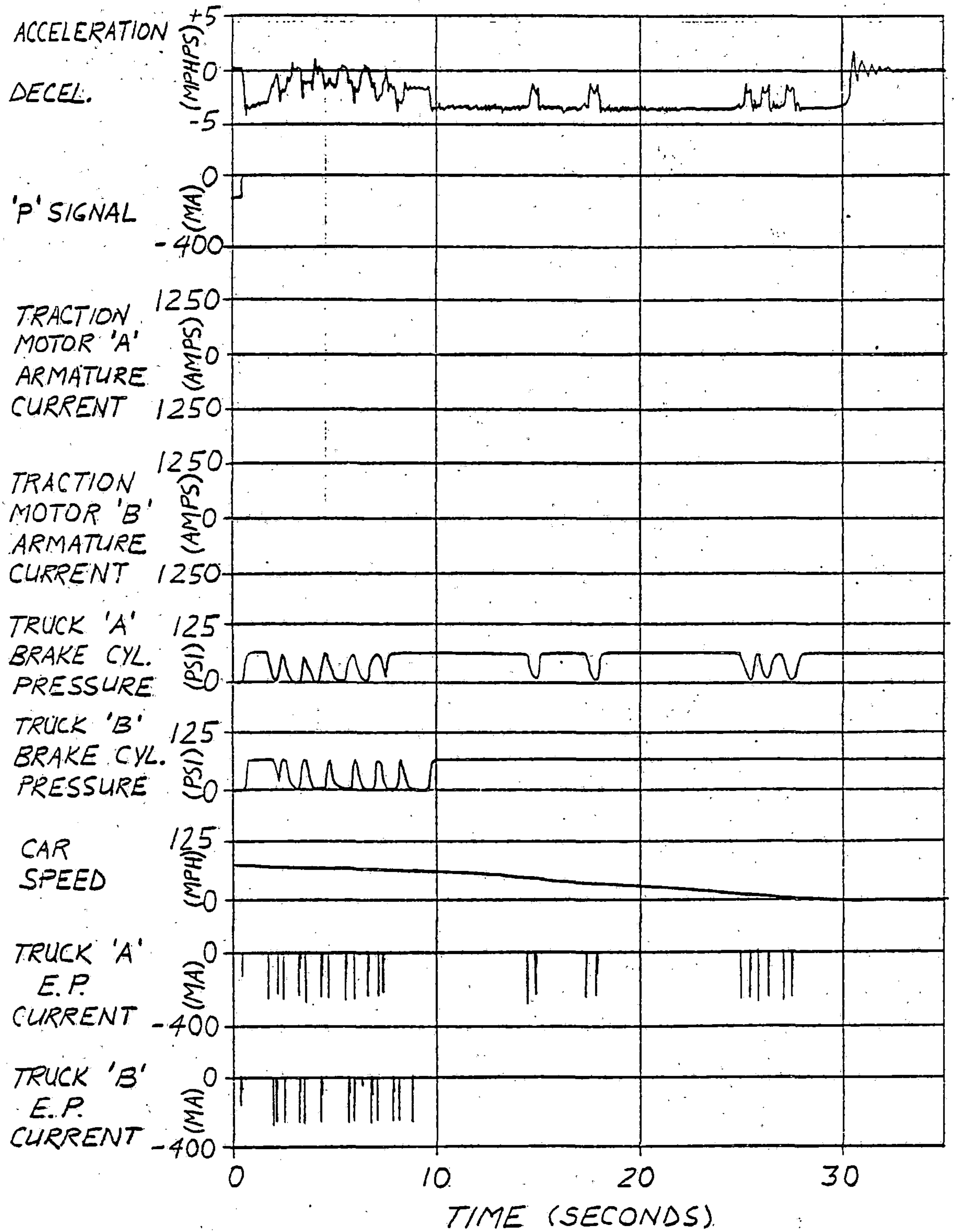


Figure 4–82. Slip-Slide Deceleration in Deadman Emergency Braking

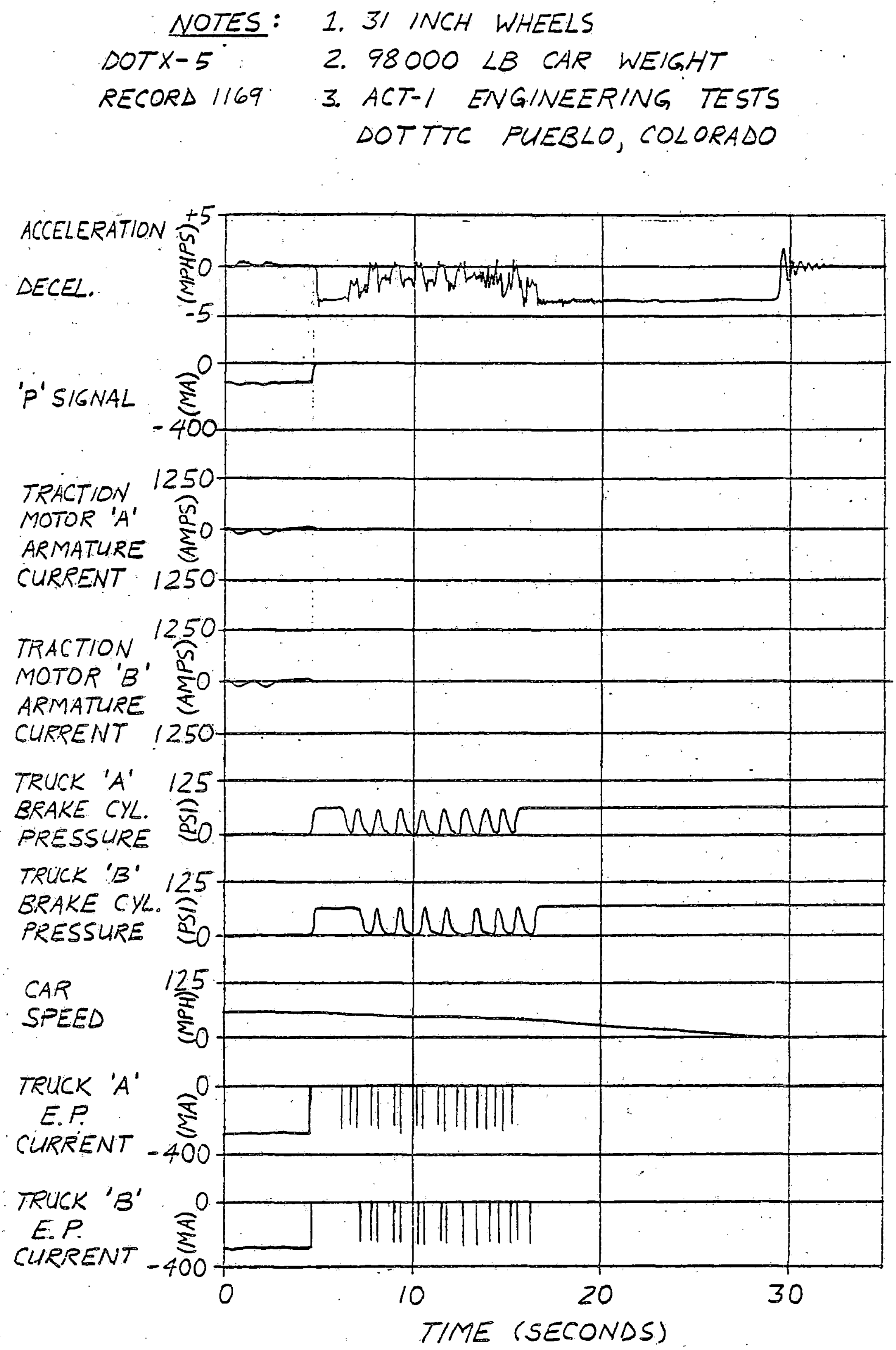


Figure 4—83. Slip-Slide Deceleration in Deadman Emergency Braking

NOTES: 1. 31 INCH WHEELS
DOTX-5 2. 98000 LB CAR WEIGHT
RECORD 1174 3. ACT-1 ENGINEERING TESTS
DOTTTC PUEBLO, COLORADO

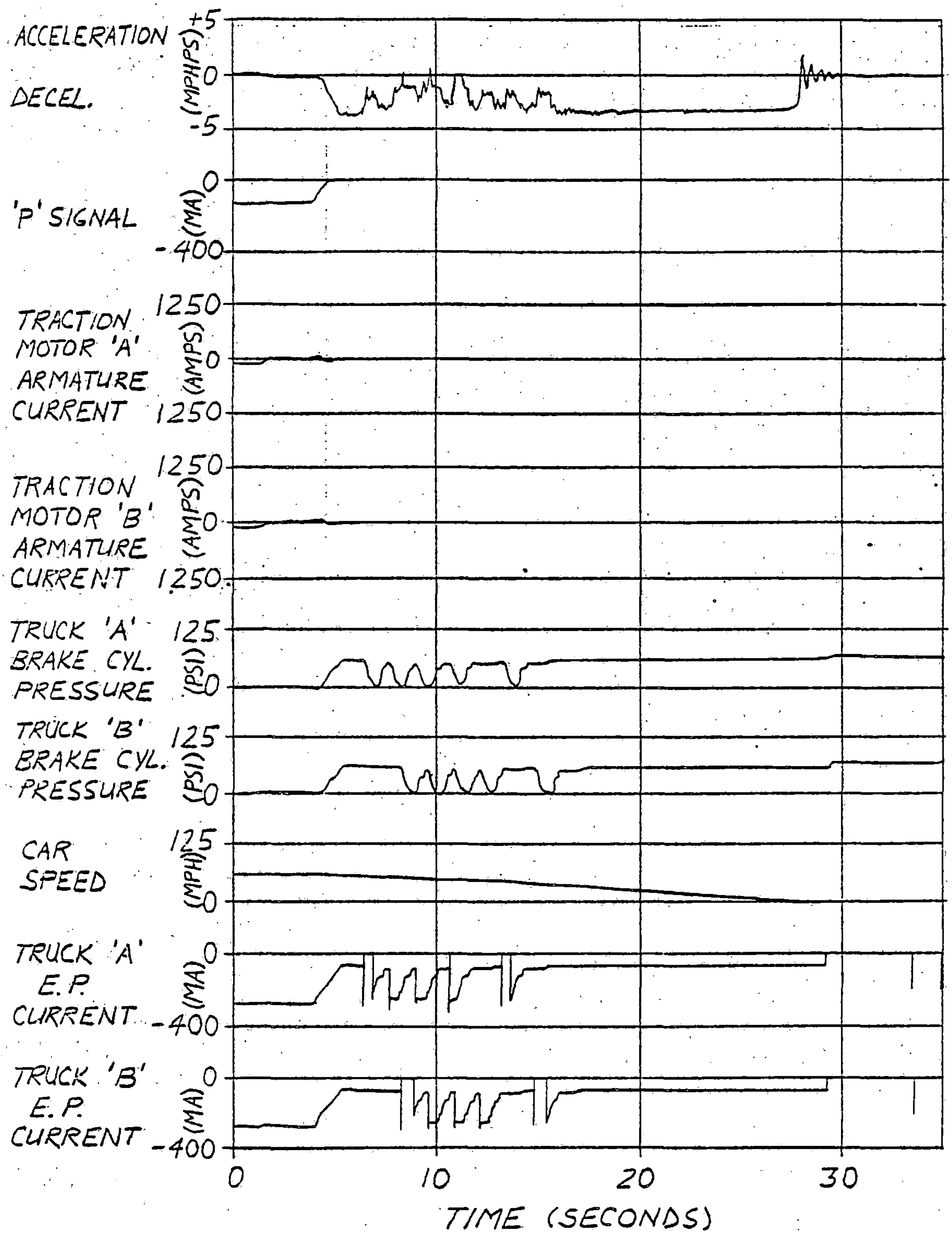


Figure 4–84. Slip-Slide Deceleration in Friction Braking

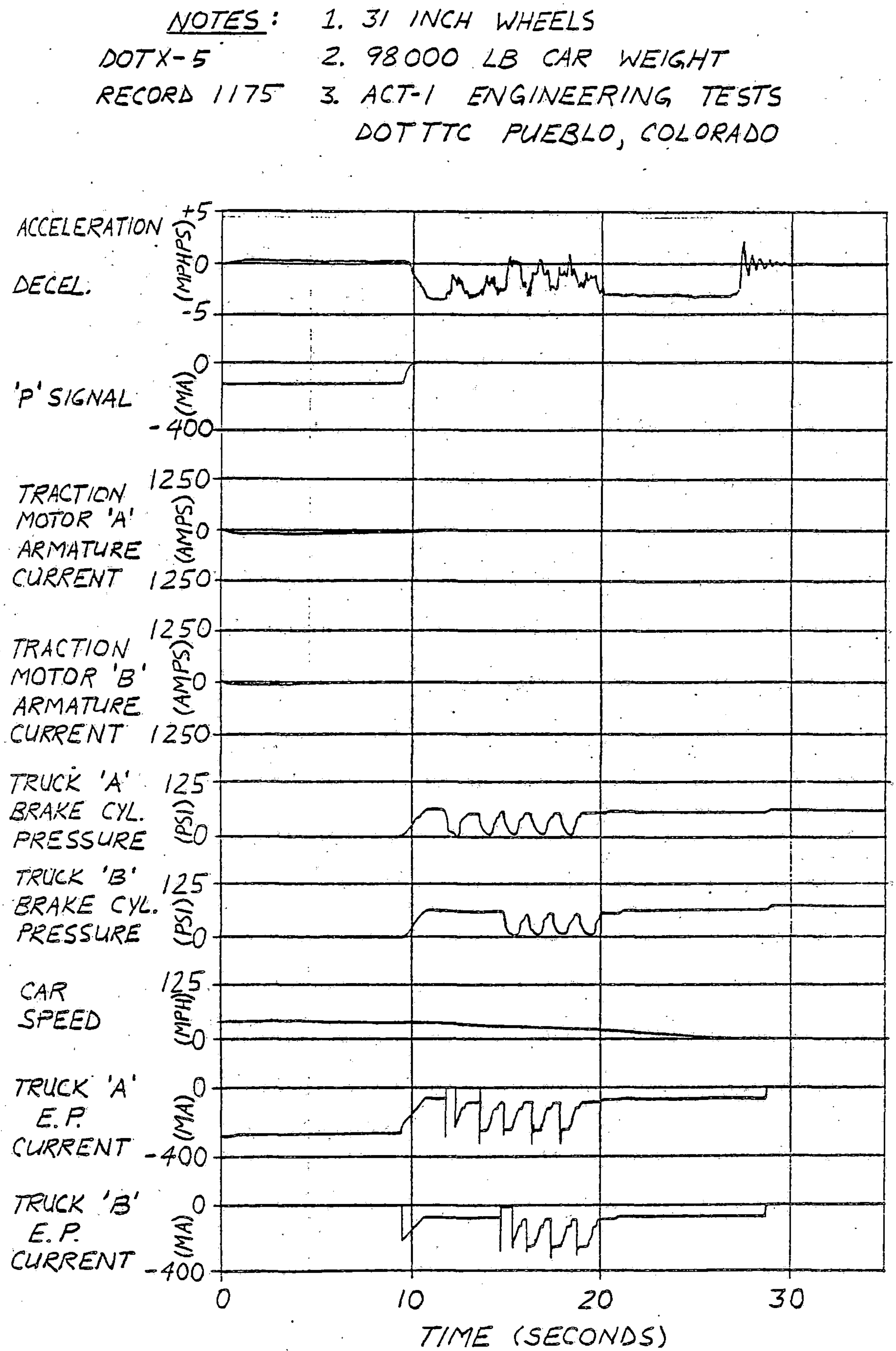


Figure 4–85. Slip-Slide Deceleration in Friction Braking

5.0 RIDE QUALITY AND STRUCTURES

5.1 SUMMARY

The ACT-1 ride quality and structures data was obtained for an AW2 weight configuration (116,000 pounds) through all sections of the transit test track (Figure 4-42). Results of a carbody shake test were used to identify significant carbody modes and a speed survey on the test track identified the speeds which excited those modes most sensitive to passenger comfort.

The ride quality data is presented in the following formats:

1. Plots of rms acceleration versus frequency at a given track section. Data at various vehicle speeds is compared with specification levels.

2. Plots of rms acceleration versus frequency at a given car speed. Data at various track sections is compared with specification levels.

3. Plots of ride roughness (g rms) versus vehicle speed for various track sections.

4. Plots of ride roughness (g rms) versus track section for various vehicle speeds.

The structures data is presented as plots of maximum alternating stress, alternating acceleration, and vertical displacement versus velocity and track section.

The shake test data for AW0, AW2, and AW3 weight configurations is presented for vertical and lateral/torsional modes. Longitudinal data is presented only for the AW0 weight configuration.

5.2 RIDE QUALITY

5.2.1 Test Objectives

The objectives of the ride quality testing were to provide ride quality baseline engineering data for the ACT-1 car at the Department of Transportation's transit test track (TTT).

5.2.2 Test Description

Ride quality tests were conducted on the ACT-1 DOTX-5 vehicle at AW2 weight for speeds of 25, 37, 50, 62, 75, and 80 mph over the six sections of the test track. Table 5-I presents a list of the test sequence record numbers used during the testing.

To delineate the rigid-body and flexible modes of vibration of the vehicle during this test series, carbody vertical, lateral, roll, pitch, and yaw vibration levels were measured with accelerometers. The output of the accelerometers was recorded on magnetic tape, with readings taken at selected locations.

The following rationale was applied to the selection of carbody accelerometer locations:

1. Forward and rear car centerline vertical accelerometers were located to obtain the effect of carbody vertical flexible modes and vertical/pitch rigid-body modes on carbody vibration.

2. A yaw angular accelerometer was used to determine the effect of rigid-body lateral/yaw modes on carbody vibration.

3. It was assumed that there was no longitudinal flexibility of the car; therefore only one longitudinal pickup was necessary to measure the rigid-body motion.

4. A roll angular accelerometer was used to determine the effect of the rigid-body roll modes on vibration.

Data was monitored on the vehicle by a test engineer using a strip-chart recorder to ensure that each accelerometer was functioning properly and to provide a quick look at selected pickups.

TABLE 5–I. TEST SEQUENCE RECORD NUMBERS

Track Section	Record Numbers (car speed-mph)					
I	1079(37),	1090(62),	1093(75),	1044(80),	1045(28),	1046(50)
II	1083(37),	1088(62),	1098(80),	1101(75),	1053(50),	1054(25)
III	1082(37),	1087(62),	1092(50),	1095(25),	1102(80),	1103(75)
IV	1081(37),	1086(62),	1091(50),	1094(25),	1097(80),	1099(75
V	1080(37),	1085(62),	1096(75),	1047(25),	1048(50),	1049(80)
VI	1080(37),	1085(62),	1096(75),	1047(25),	1048(50),	1049(80)

5.2.3 Instrumentation

Schaevitz LSBC accelerometers were selected to measure vibration levels because they have an effective measurement capability in the desired frequency range of 0.1 to 50 Hz.

Accelerometers used to measure car floor vibrations were mounted to plates having pointed legs to pierce the carpet and make direct contact with the floor structure. Truck accelerometers were mounted to brackets rigidly attached to the journal boxes and traction motors.

Vibration pickup locations are shown in Table 5-II.

TABLE 5–II. RIDE QUALITY ACCELEROMETER LOCATIONS

Parameter	Direction	Range	Frequency (Hz)
Car Body			
Linear accelerations			
Floor sta 791 centerline	Vertical	±0.40 g	200
Floor sta 491 centerline	Vertical	±0.40 g	200
Floor sta 648 centerline	Vertical	±0.40 g	200
Floor sta 791 centerline	Lateral	±0.40 g	200
Floor sta 491 centerline	Lateral	±0.40 g	200
Angular accelerations			
Floor sta 491 centerline	Roll	2 rad/sec^2	50
Floor sta 491 centerline	Pitch	1 rad/sec^2	50
Floor sta 491 centerline	Yaw	1 rad/sec^2	50
Truck			
Linear accelerations			
Aft truck transom centerline Traction motor swing mount	Vertical	±4 g	200
Aft truck fwd axle housing right side	Vertical	±20 g	200
Aft truck traction motor left swing end	Vertical	±4 g	200

5.2.4 Test Procedures

The procedures followed during ride quality testing were as follows:

1. Steady-speed runs (ACT-R-1101-TT-AT)
   a. Patch in ride quality instrumentation.
   b. Accelerate to and maintain test point speed.
   c. Prior to entering a test section, start recorders and mark tapes and data sheet with record number.
   d. Provide event mark on tapes at beginning of test section (see attached test section locations).
   e. Provide event mark at end of 20 seconds of record.

f. Stop recorders.

g. Proceed to next section or speed and repeat the above steps.

2. Acceleration run

a. Proceed to start location and stop vehicles, location 120 cw or 150 ccw.

b. Start recorders and provide record number.

c. Initiate and maintain full acceleration.

d. Provide event mark at first motion.

e. Provide event mark at 40-mph indicated speed.

f. Stop recorders.

g. Stop vehicle.

5.2.5 Test Results

5.2.5.1 Ride Quality Results

The ride quality vibration data was recorded on analog tapes and later reduced to obtain g rms versus frequency plots for selected 10-second samples. These plots were then used to identify the significant modal response characteristics of the carbody structure for comparison with specification requirements. Ride quality data presented in this report shows the effect of vehicle speed and track section variations.

The ride quality data was further processed to produce a ride roughness plot which is a figure of merit to indicate the roughness of ride experienced by the passenger.

5.2.5.1.1 Effect of Speed – Figures 5-1 through 5-15 compare ACT ride quality data to the goals for both lateral and vertical acceleration at the six vehicle speeds tested.

Carbody vertical vibrations at the rigid-body suspension frequencies (1 Hz to 2.5 Hz) and carbody bending frequencies (6.5 Hz to 14 Hz) are close to meeting the vertical ride quality specification. This specification is more stringent than the State-of-the-Art Car (SOAC) ride quality requirements. ACT vertical vibrations are significantly lower than those measured on SOAC and would meet the SOAC goal. Lateral carbody vibrations, however, are significantly above the specification requirement. This data would not meet the SOAC goal and is higher than SOAC levels at comparable speeds and carbody locations.

5.2.5.1.2 Effect of Track Section – Figures 5-16 through 5-30 compare ACT ride quality data to the goals for both lateral and vertical accelerations over the six test track sections. Acceleration levels are higher on track section III, jointed rail on wood ties.

5.2.5.2 Ride Roughness Results

The ride quality vibration data was further processed to produce the ride roughness data shown on the following baseline comparison plots. Ride roughness is a figure of merit to indicate the roughness of ride experienced by a typical passenger on a moving transit vehicle. The methodology for establishing this parameter is defined in GSP-064, "General Vehicles, Test Plans for Urban Rail Transit Cars." The actual response of the shaper for the horizontal and vertical signal weighting is shown in Figures 5-31 and 5-32, respectively.

5.2.5.2.1 Effect of Speed – Figures 5-33 through 5-37 present ride roughness versus vehicle speed. This data shows increased vibrations with increasing vehicle speed. The peak which occurs at 37 mph at the vertical pickup locations results from response of the first carbody vertical bending natural frequency (6.5 Hz) excited by the wheel out-of-round inputs at the same frequency.

5.2.5.2.2 Effect of Track Section – Figures 5-38 thru 5-42 present ride roughness versus track section. This data shows that vibrations at all speeds and carbody locations are comparable at each of the six track sections.

5.3 STRUCTURES

5.3.1 Test Objectives

The purpose of examining the structural integrity of railcar trucks is to determine if strain levels, excessive motions, or resonant vibrations exist within the assembly which are significant with respect to their effect on the useful life and function of the various components.

5.3.2 Test Description

The ACT-1 truck (Figure 5-43) is a bolsterless design; the carbody interface is accomplished through a solid bearing in the suspension adapter. This bearing provides the truck's turning capability while supporting the carbody weight and transferring the lateral and longitudinal loads from the truck into the carbody.

Vertical and lateral loads between the suspension adapter and truck frame are carried by the four secondary-suspension air springs. The loads are predicted by monitoring the vertical and lateral displacements across these elements and used in conjunction with the published spring-rate data.

The truck frame employs a balljoint equalization scheme; the primary suspension elements at the journal bearings take the form of elastomeric sleeves of relatively high spring rate. Measurement of deflection across these elements, both in the vertical and lateral directions, gives a measure of the load transferring through this interface.

The carbody roll characteristics are measured by recording directly the truck rollbar loading with a load-calibrated strain gage mounted on that member. Carbody accelerations are recorded to gain knowledge and to permit correlation with computer-aided predictions of total car response.

The strain in the truck structure was monitored in selected areas identified as critical in the qualification fatigue test program to ensure safety of operation and correlation with analytical predictions.

Data has been collected only at 116,000 pounds (AW2) weight. Speeds of 20, 40, 60, and 80 mph were recorded for the six track sections on the UMTA rail transit test track.

5.3.3 Instrumentation

The structural instrumentation consisted of the strain gages, accelerometers and displacement transducers as shown in Table 5-III.

TABLE 5–III. ACT-1 STRUCTURAL INSTRUMENTATION SYSTEM TEST PARAMETERS

Channel	Parameter	Calibration Range
1	Carbody sta 648, vertical acceleration	0.4 g
2	Carbody sta 791, vertical acceleration	0.4 g
3	Carbody sta 491, vertical acceleration	0.4 g
4	Carbody sta 491, lateral acceleration	0.4 g
5	Carbody sta 791, lateral acceleration	0.4 g
6	Strain gage, suspension adapter	500 μ e/inch
7	Strain gage, radius rod arm bracket	500 μ e/inch
8	Strain gage, side frame, core plug	500 μ e/inch
9	Strain gage, side frame, lateral bracket	500 μ e/inch
10	B truck rollbar torque	10,000 lb
11	B truck motor, vertical acceleration	4.0 g
12	B truck motor, vertical acceleration	10.0 g
13	B truck motor, lateral acceleration	4.0 g
14	B truck diff housing, vertical acceleration	10.0 g
15	B truck swing mount, vertical acceleration	4.0 g
16	B truck journal, lateral displacement	0.25 inch
17	B truck left journal, vertical displacement	0.25 inch
18	B truck right journal, vertical displacement	0.25 inch
19	B truck housing, vertical acceleration	20.0 g
20	B truck frame, left, vertical acceleration	20.0 g
21	B truck frame pedestal, vertical acceleration	4.0 g
22	B truck left airspring, vertical displacement	1.75 inches
23	B truck right airspring, vertical displacement	1.75 inches
24	B truck right airspring, lateral displacement	1.75 inches
25	Car speed (mph)	0-80 mph

5.3.4 Test Procedures

a. Ballast the car to the test weights.

b. Calibrate the instrumentation. A constant oscillograph trace deflection at a selected standard voltage is obtained for each circuit.

c. After the instrumentation is calibrated, the car is operated around the test track at one of the test speeds of 20, 35, 50, 60, or 80 mph. When the car is approaching the selected track section at the required speed, the tape recorders are started. The recorder event marker is used at the appropriate point. A record of 15 to 20 seconds duration is obtained.

d. A log of the data recorded is made showing run number, speed, event marker position on the track, and the time of day.

e. The tape-recorded data is continuously played back through an oscillograph operating at the paper speeds required to verify frequencies and amplitudes. The run number, test speed, position on the track, and any deficiencies are noted on the oscillograph paper.

f. After completion of the initial speed run, the oscillograph records are reviewed and deficiencies are corrected.

g. Steps c through e are repeated for each speed and test location listed in the test plan.

h. The posttest calibration is performed.

5.3.5 Test Results

The structural stress data parameters were recorded on analog tapes and played back through an oscillograph to obtain strip charts. A listing of all structural data records taken on ACT-1 at the transportation test center is presented in Table 5-IV.

A sample data record is presented in Figure 5-43. Plots of maximum alternating stress, alternating acceleration, and vertical displacement versus velocity and track section are shown in Figures 5-44 through 5-47.

Figure 5-43 presents oscillograph data record strip charts showing the structural data collected during a 7-second record (no. 1072) at 60 mph, T16 switch in Section I at the car weight of 116,000 pounds. The figure indicates the response of the various truck elements when subjected to a high-speed perturbation in the rail.

TABLE 5–IV. SUMMARY OF STRUCTURAL TEST POINTS

Record	Track Position	Speed (mph)				
		20	40	60	70	80
1057	T32 – T30	X				
1058	T24 – T21			X		
1059	T16 switch		X			
1060	T5 crossing			X		
1061	T49 – T45	X				
1062	T40 – T38		X			
1063	T33 – T30			X		
1064	T24 – T21		X			
1065	T5 crossing		X			
1066	T49 – T45		X			
1067	T40 – T38	X				
1068	T33 – T30		X			
1069	T24 – T21	X				
1070	T50 – T44			X		
1071	T40 – T36			X		
1072	T16 switch			X		
1073	T5 crossing	X				
1074	T16 switch	X				
1075	T15 – T11	X				
1076	T15 – T11			X		
1077	T15 – T11		X			
1078	T5 – T18					X
	T18 – T5				X	

Figure 5-44 shows the maximum alternating stress measured in the truck side frame at 80 mph for the six different track, fastener tie, and ballast combinations. Two conclusions that might be drawn from this limited data sample are that wooden ties produce less stress than the concrete ties (Section I and II compared to IV, V, and VI) and that welded rail on wood ties (Section I) produces less truck shock than jointed rail on wood ties (Section III).

The effect of track roughness on the truck frame stresses is shown in Figure 5-44 as Notes 1 and 2. Note 1 is data recorded at 70 mph in the perturbed area of Section I; Note 2 is in the Section I unperturbed area, also at 70 mph.

The stiff primary springs of this type of articulated truck do not attenuate the rail-induced shock loads to any high degree. The 50-percent increase in stress, to the 5,400-psi level, might be a source of concern in a welded, production-type truck.

Figure 5-46 shows the increase in maximum stress, at the same side frame location as previously discussed, as a function of speed. The data is recorded at track Section III, marker 320. The nominal trend of increasing stress with speed is observed. Weight trends were not possible since only the 116,000 pound gross weight was tested.

Figure 5-47 shows the variation in vertical acceleration of the B-truck traction motor with speed. The apparent deadband below 20 mph and the linear relationship above 20 mph both are apparently responses peculiar to this design.

Figure 5-48 shows the increase in airspring vertical displacement in relation to speed. The data shown is for track Section I; the perturbation is directly associated with switch T16.

5.4 SHAKE TEST

5.4.1 Test Objectives

The purpose of the ACT-1 dynamic shake test was to determine the vertical carbody flexible natural frequencies and mode shapes in the 3-Hz to 20-Hz frequency band.

Information learned from the dynamic shake tests is essential for interpreting and evaluating ride quality test data and determining if vehicle operation would be degraded by any resonant condition in the 80-mph maximum speed envelope.

Carbody bending modes can be excited by sinusoidal forces at the wheel rotational frequency produced by wheel eccentricities. These wheel eccentricities result from the difference between the actual center of rotation and the true wheel center. Although this misalignment is extremely small, typically 0.005 to 0.010 inch for a rapid transit vehicle, the resulting sinusoidal force is sufficient to cause a lightly damped carbody structure to vibrate at levels which degrade the overall vehicle ride quality.

Another source of periodic excitation comes from track joint spacing. Jointed track which is commonly 39 feet long is installed with left-to-right joints staggered. This produces both a rail joint and a 2X rail joint periodic excitation into the vehicle. The wheel first rotational and jointed-track input frequency spectrum versus vehicle speed for the ACT-1 are presented in Figure 5-49.

5.4.2. Test Description

These tests were conducted on the ACT-1 DOTX-5 carbody at the AW0, AW2, and AW3 car weights. To insure total system integrity, the shaker and accelerometers were checked daily for correct phase and amplitude relationships. This was done by attaching all accelerometers at the shaker baseplate and sweeping from 3 Hz to 20 Hz. Evaluation of this trace insured that the entire system was functioning properly. R-cals were taken daily and at the start and finish of a test block. The anticlimber vertical installation of the shaker is shown in Figure 5-50. For each test configuration, frequency sweeps of acceleration were obtained from 3 Hz to 20 Hz in 0.5-Hz increments. These sweeps were used to construct acceleration-versus-frequency curves from which the system natural frequencies were determined. A typical acceleration-versus-frequency curve adjusted to a constant 500-pound shaker force is presented in Figure 5-51. Detailed probes of the carbody structure were then performed at the natural frequencies to determine the associated mode shapes.

The ballast distribution for the AW2 and AW3 car test weight conditions is presented in Figure 5-52. For the AW2 test configuration, 509 lead weights for a total of 25,000 pounds of ballast were added. To achieve the AW3 weight, an additional 328 weights were added for a grand total of 40,750 pounds of ballast.

5.4.3 Instrumentation

Linear servo-type Shaevitz and Statham accelerometers were used to measure the dynamic response of the ACT-1 vehicle. Three accelerometers had a ±2g sensitivity while one accelerometer, usually located at the shaker, had a ±10-g sensitivity. These accelerometers were mounted to rigid metal brackets which were easily moved and attached to the structure by C-clamps or secured to the carbody floor with sand bags or lead weights. Sinusoidal excitation forces were supplied by an electric Lazan Model LA1 shaker. The force-versus-frequency characteristics of this shaker device are shown in Figure 5-53. The accelerometer outputs were conditioned and recorded on a six-channel Honeywell Visicorder Model 906B oscillograph. The test equipment block diagram illustrating the arrangement of the shaker, drive motor, power supply, and signal conditioning is shown in Figure 5-54.

5.4.4 Test Results

5.4.4.1 Vertical Shake

Test results of the vertical shake test show four significant bending modes as summarized in Figure 5-55. The vertical mode shapes for AW0, AW2, and AW3 weight configurations are shown in Figures 5-56 through 5-58, respectively.

5.4.4.2 Lateral Shake

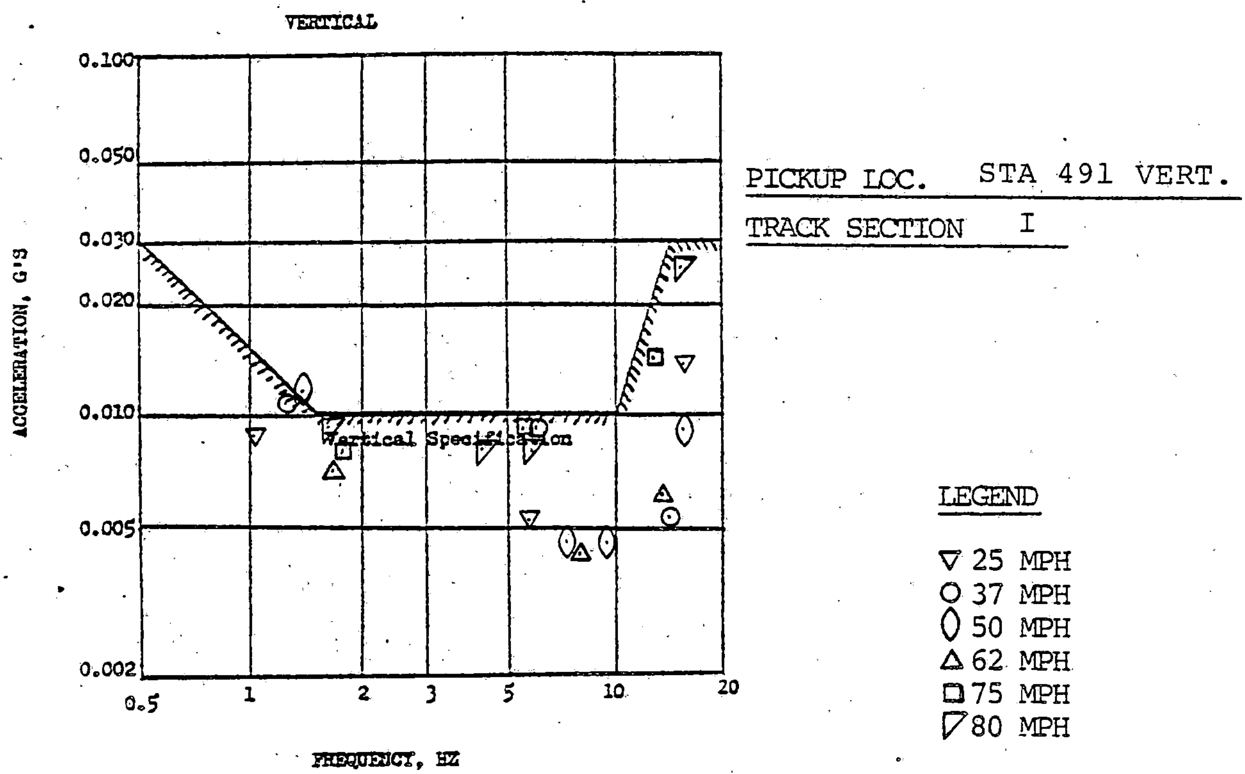
Test results of the lateral/torsional mode show the first mode is controlled by lateral bending in the classicial free-free first mode shape with only a small amount of torsion. A second mode was identified at the AW3 weight, but this mode was above the 20-Hz shaker capability at the lower weights. The mode shapes for AW0, AW2, and AW3 weights are presented in Figures 5-59 through 5-61, respectively.

5.4.4.3 Longitudinal Shake

The ACT-1 shake test program defined the longitudinal modes of the carbody-mounted equipment at the AW0 test weight.

The carbody longitudinal shake test showed that the A-end ESU had a natural frequency at 16 Hz.

These tests show that the ACT-1 vehicle does not have any longitudinal equipment resonances within its operating speed range up to 80 mph, since the lowest longitudinal frequency of 16 Hz for the A-end ESU is above the wheel first rotational frequency.



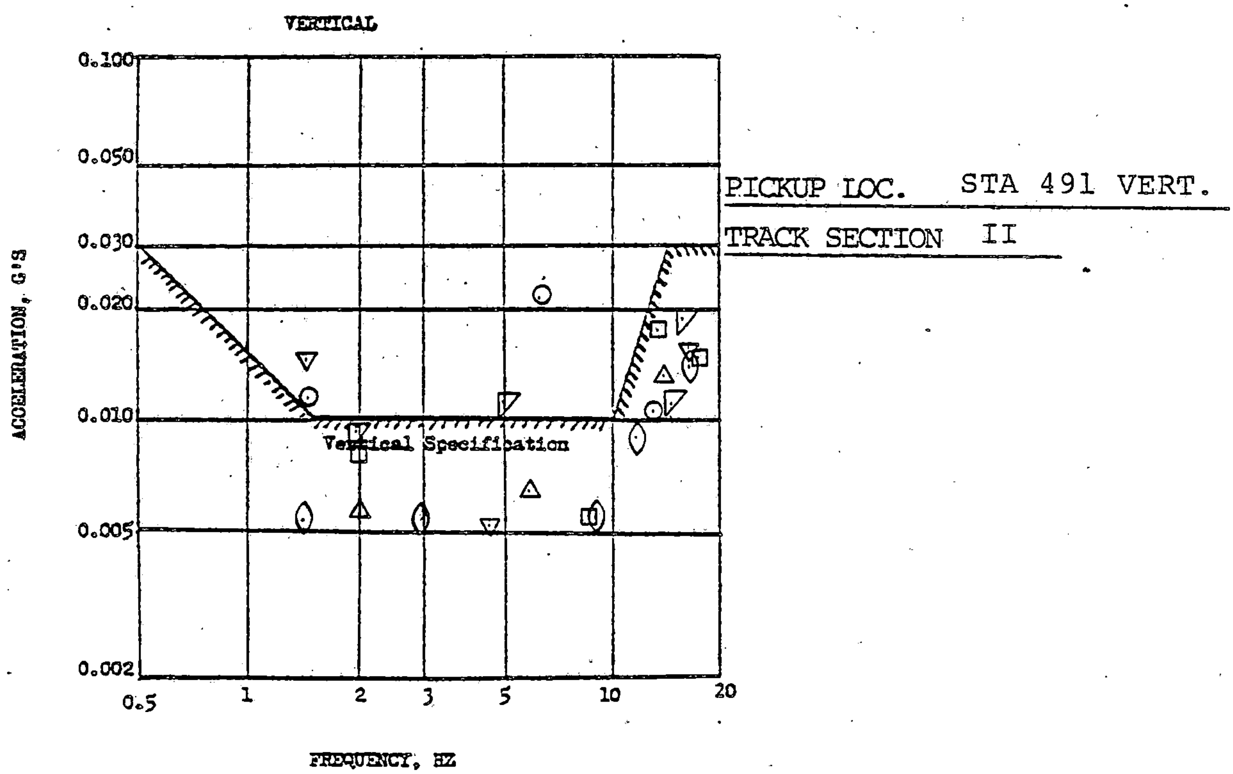


Figure 5–1. Ride Quality Comparison to Goals: Speed Effect at Station 491 Vertical

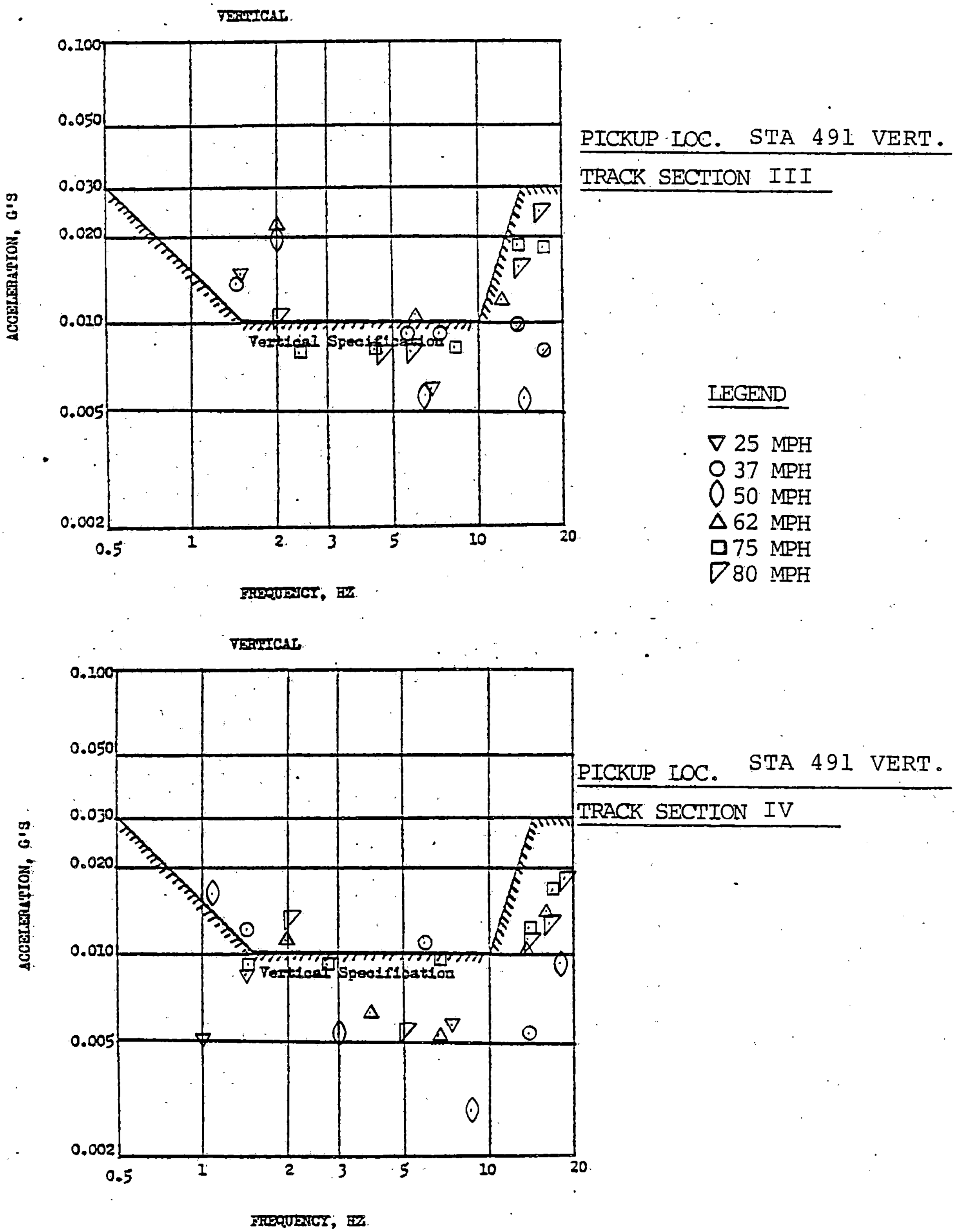


Figure 5–2. Ride Quality Comparison to Goals: Speed Effect at Station 491 Vertical

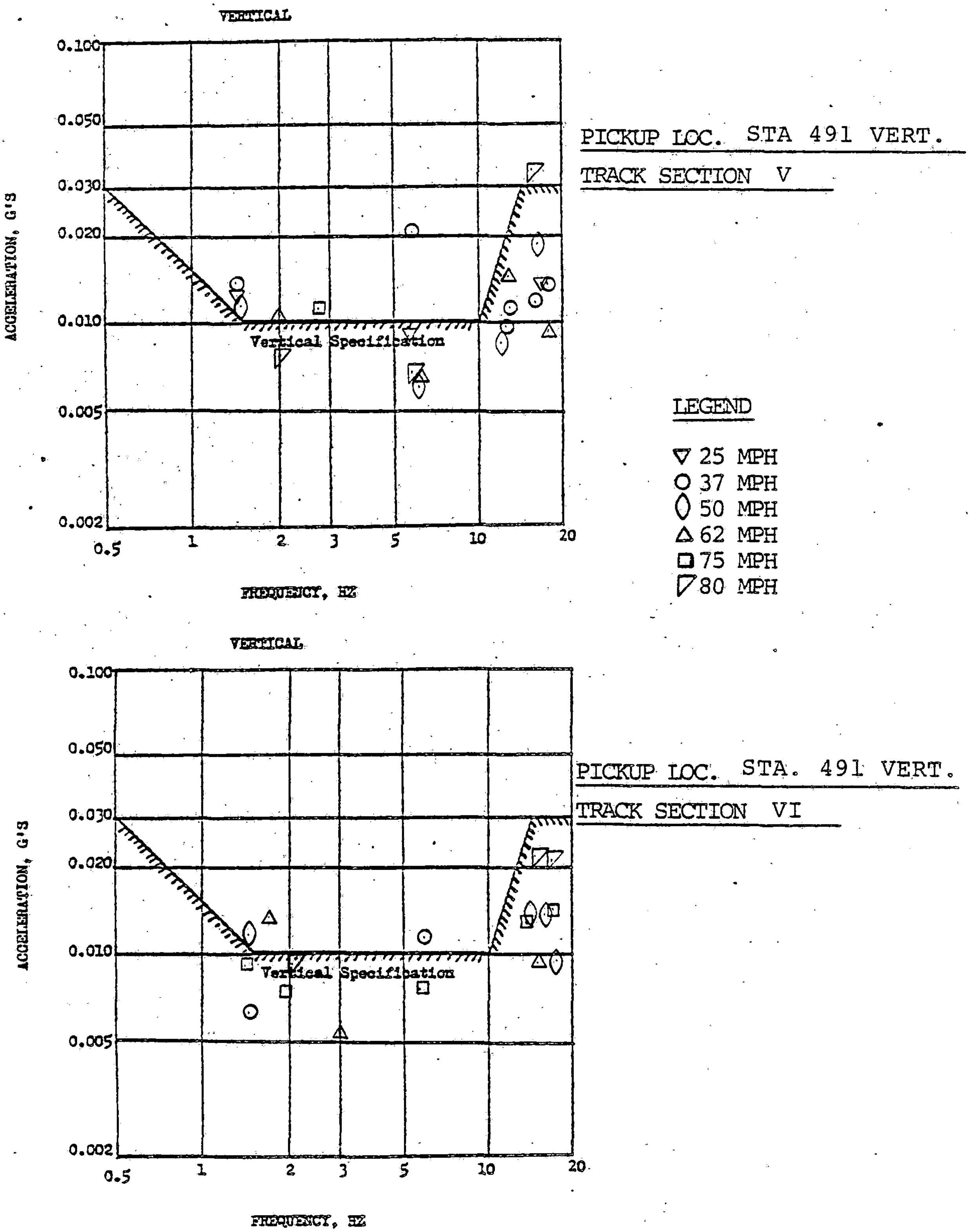


Figure 5–3. Ride Quality Comparison to Goals: Speed Effect at Station 491 Vertical

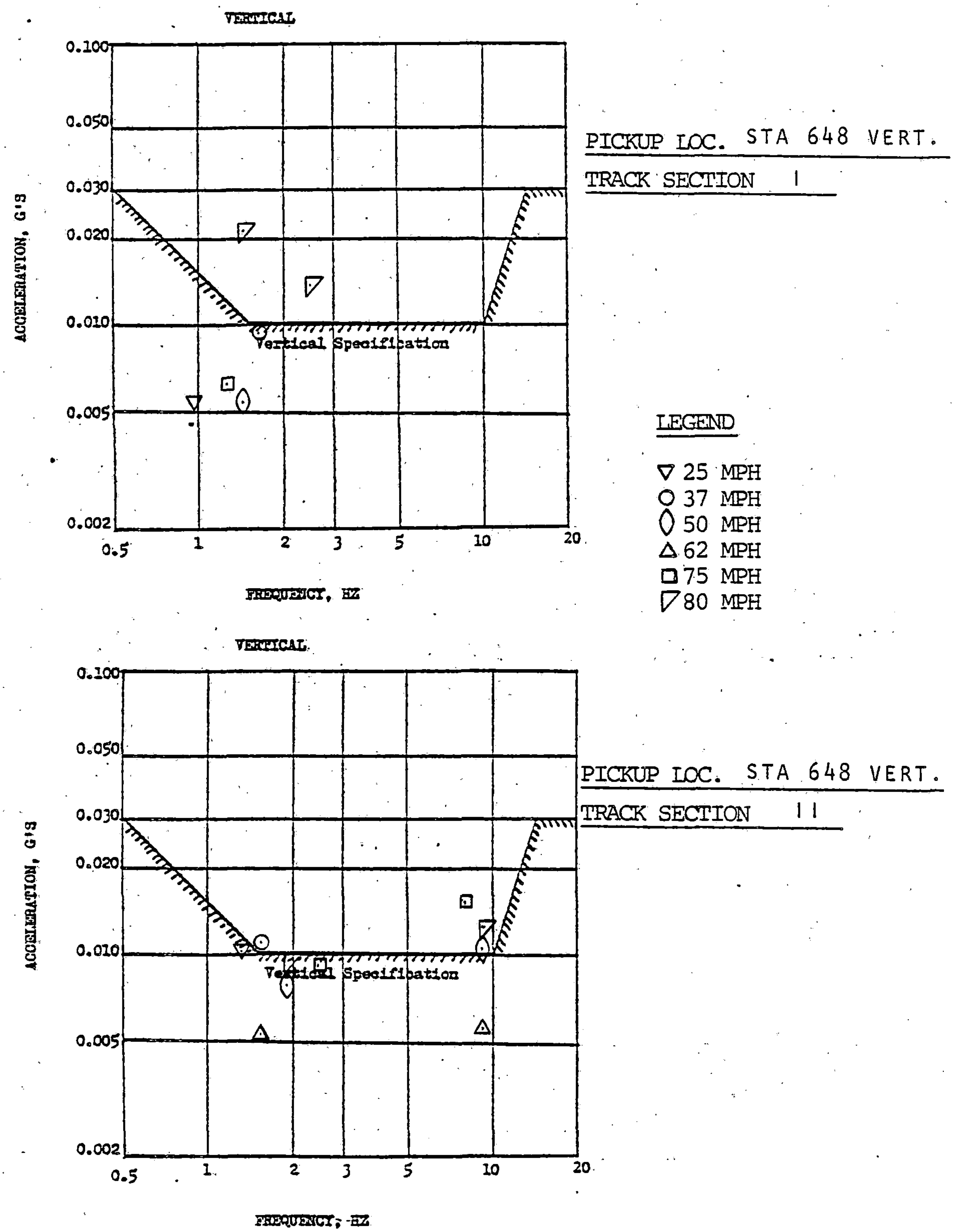
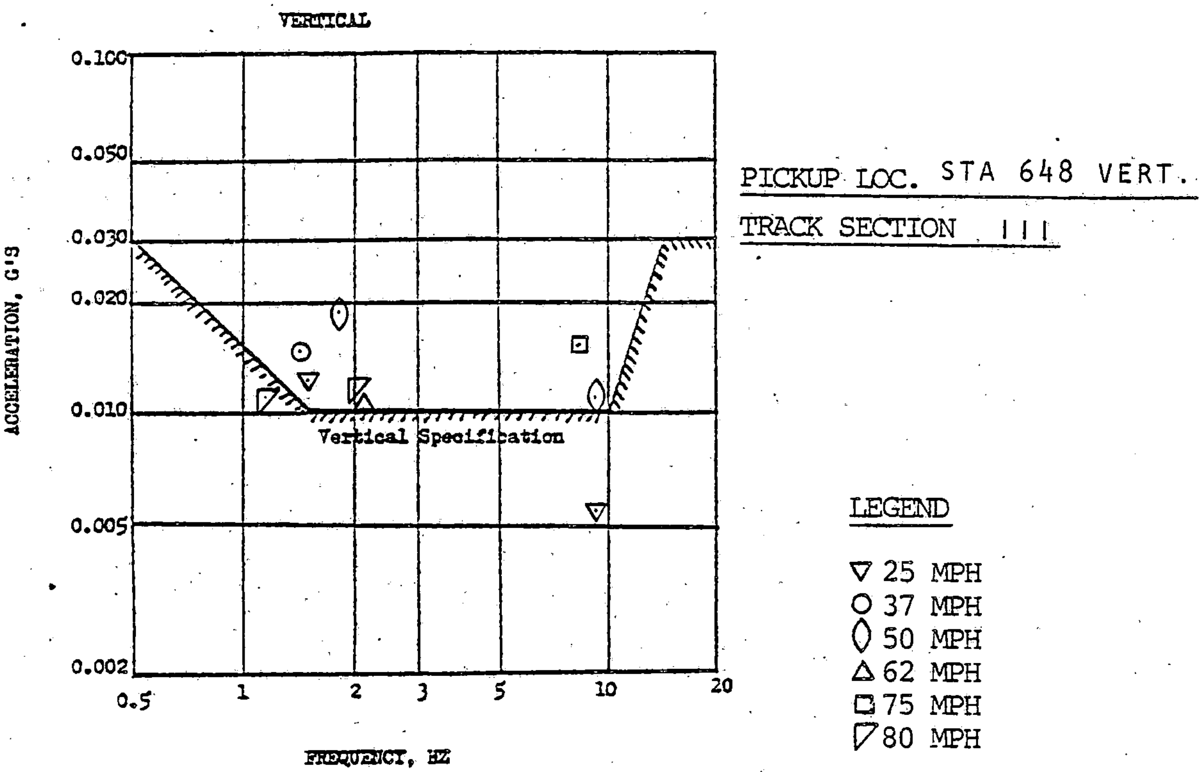


Figure 5–4. Ride Quality Comparison to Goals: Speed Effect at Station 648 Vertical



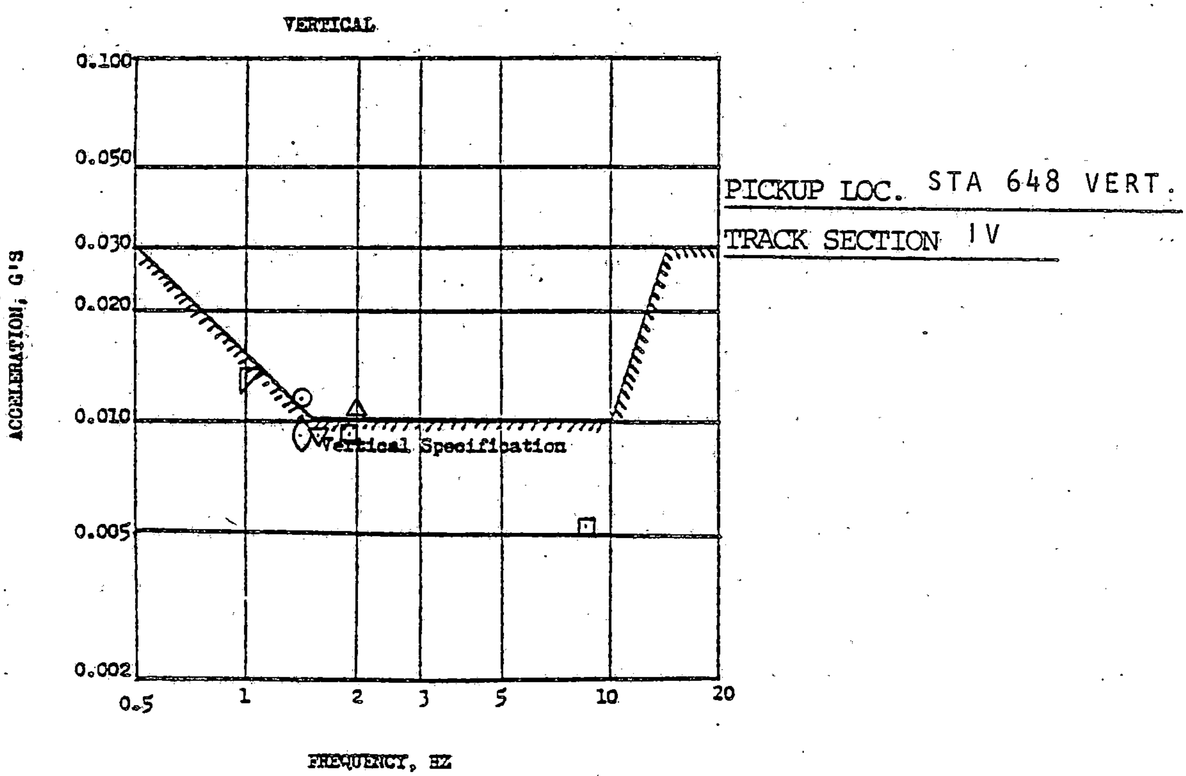


Figure 5–5. Ride Quality Comparison to Goals: Speed Effect at Station 648 Vertical

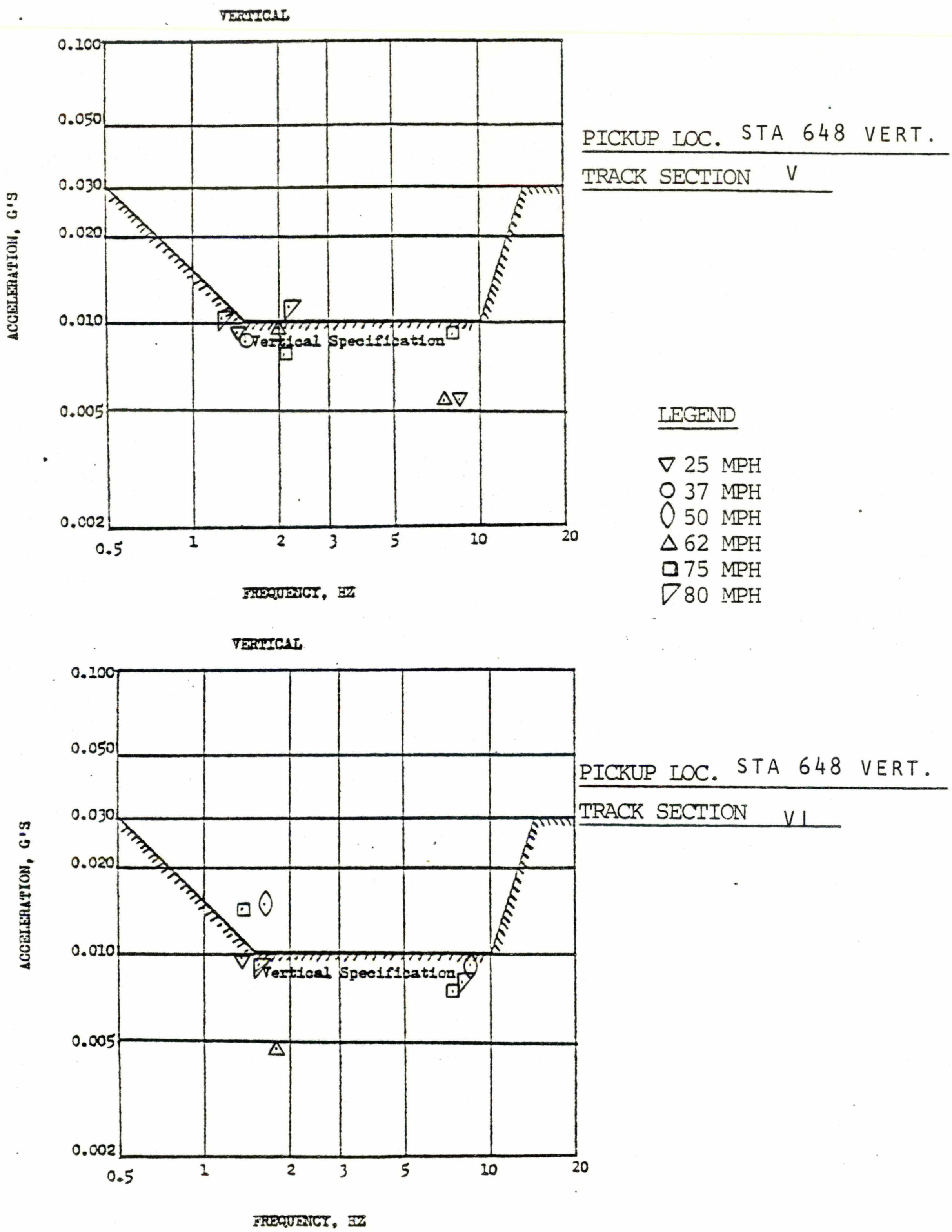


Figure 5–6. Ride Quality Comparison to Goals: Speed Effect at Station 648 Vertical

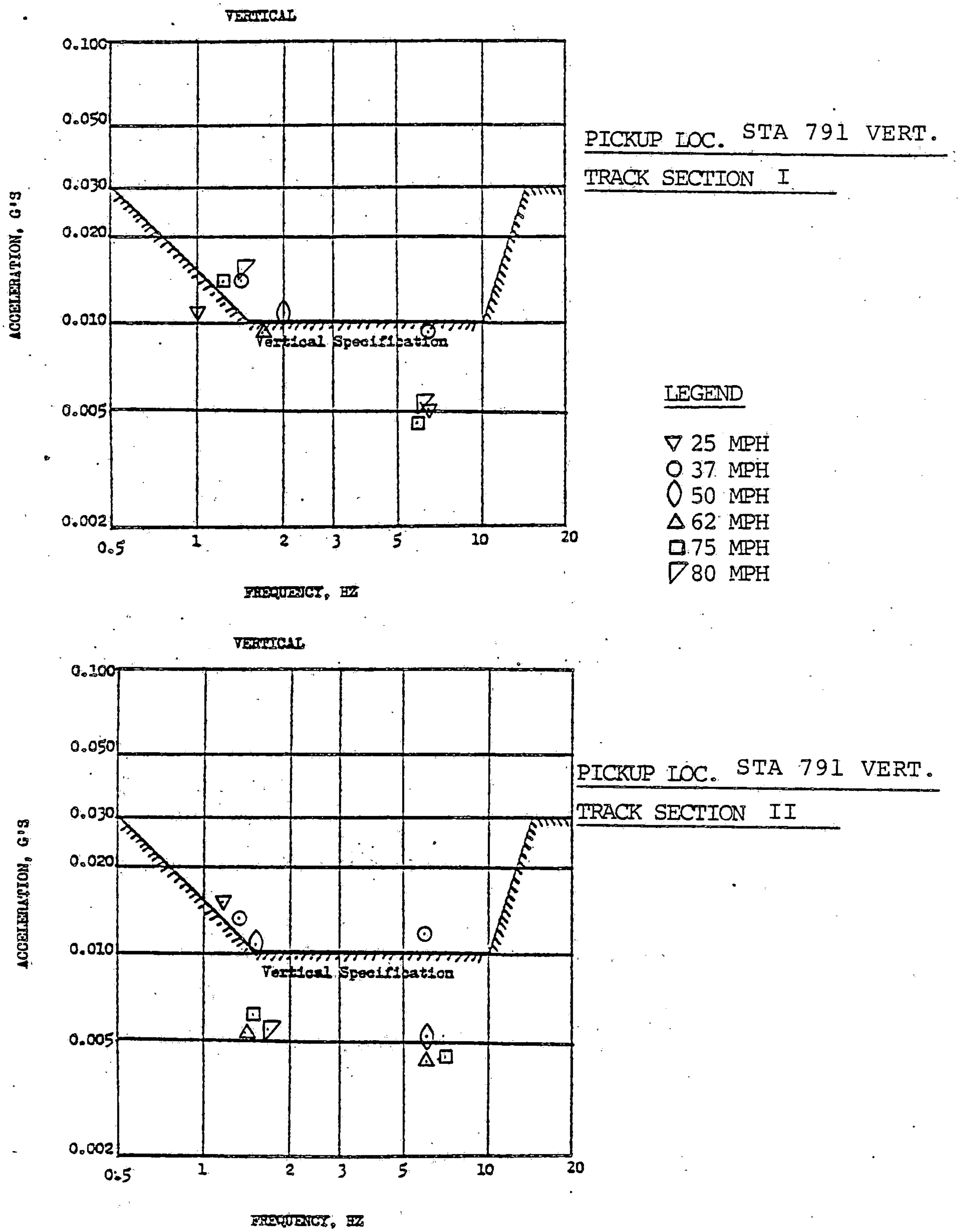


Figure 5–7. Ride Quality Comparison to Goals: Speed Effect at Station 791 Vertical

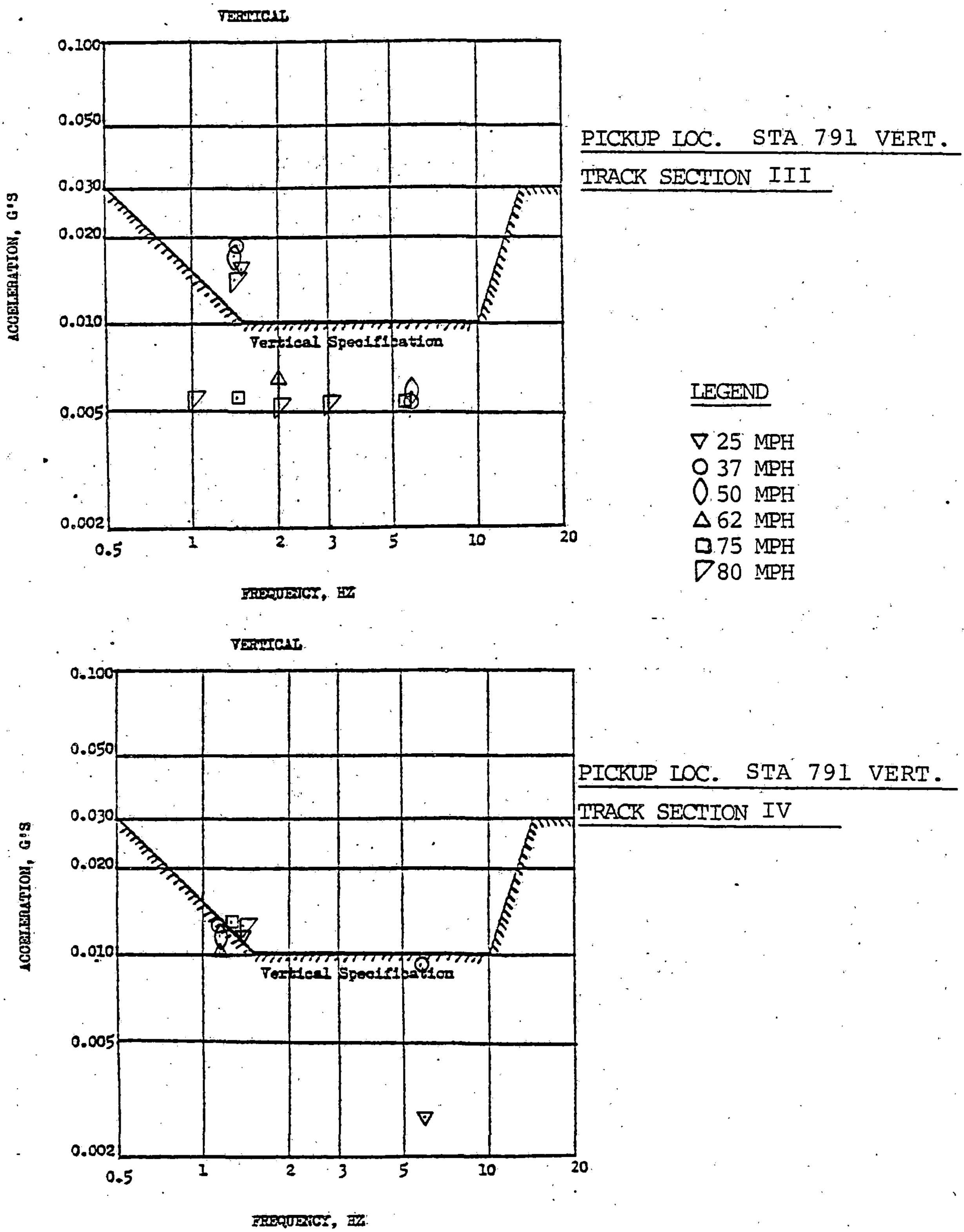


Figure 5–8. Ride Quality Comparison to Goals: Speed Effect at Station 791 Vertical

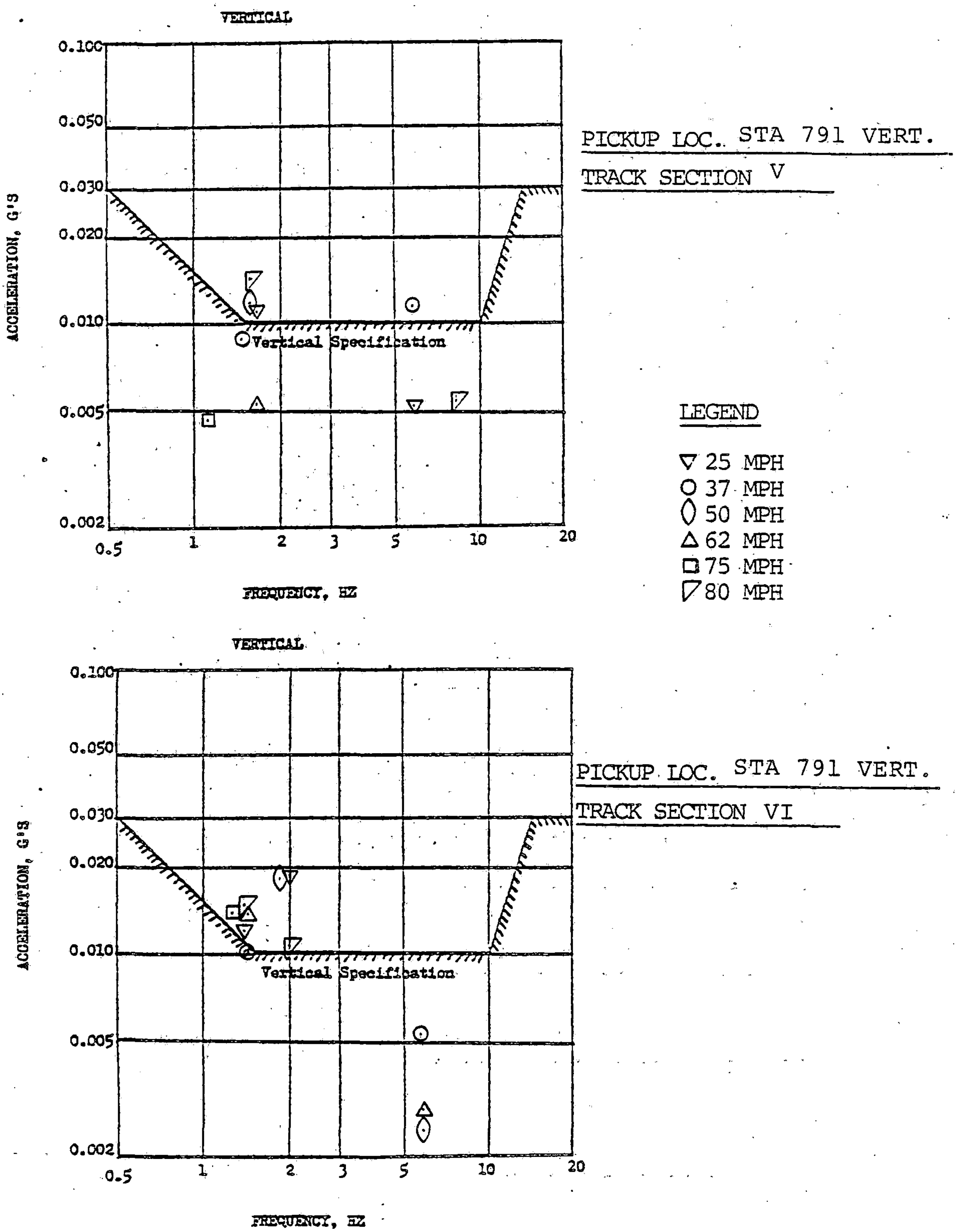


Figure 5–9. Ride Quality Comparison to Goals: Speed Effect at Station 791 Vertical

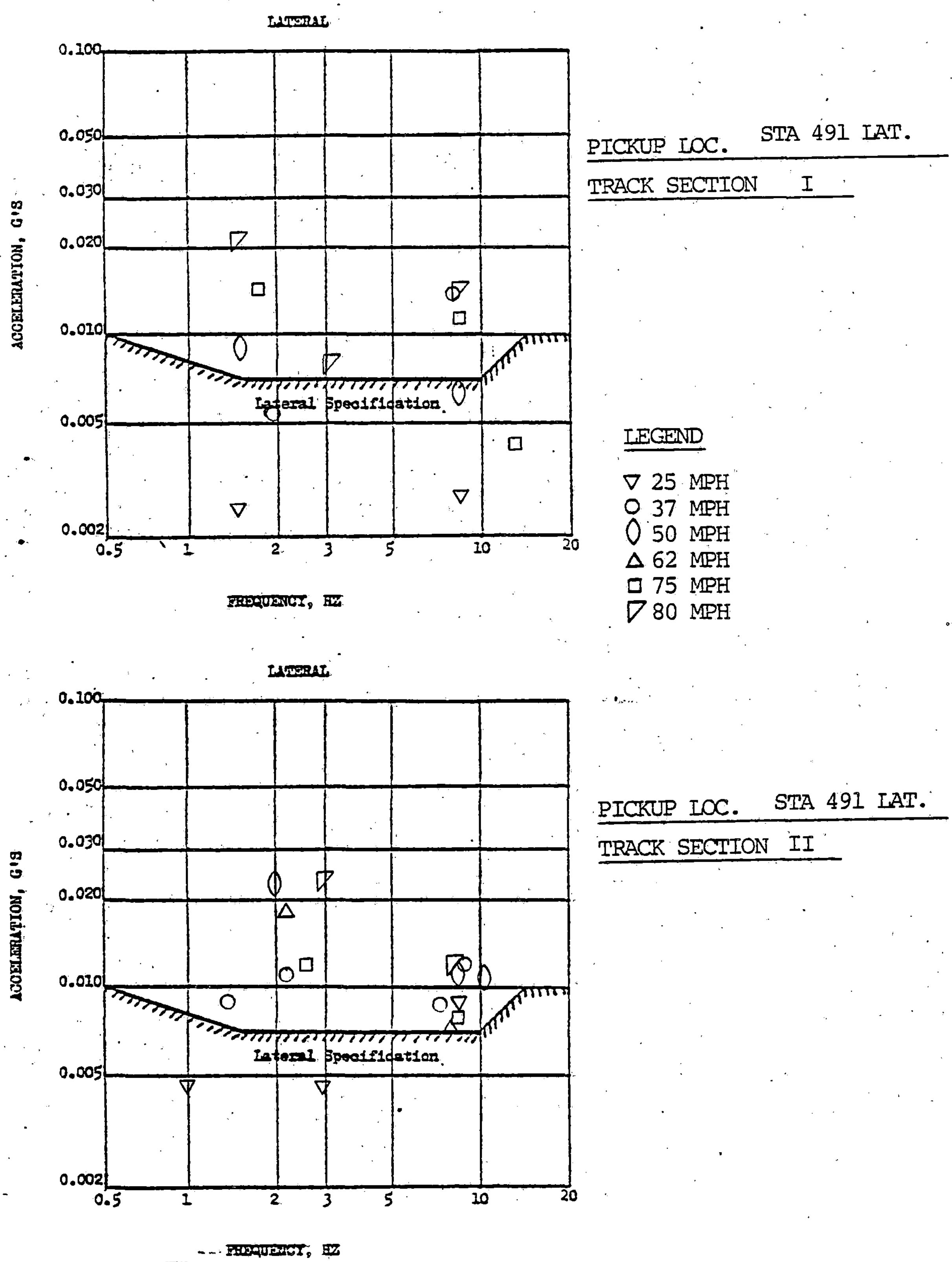


Figure 5–10. Ride Quality Comparison to Goals: Speed Effect at Station 491 Lateral

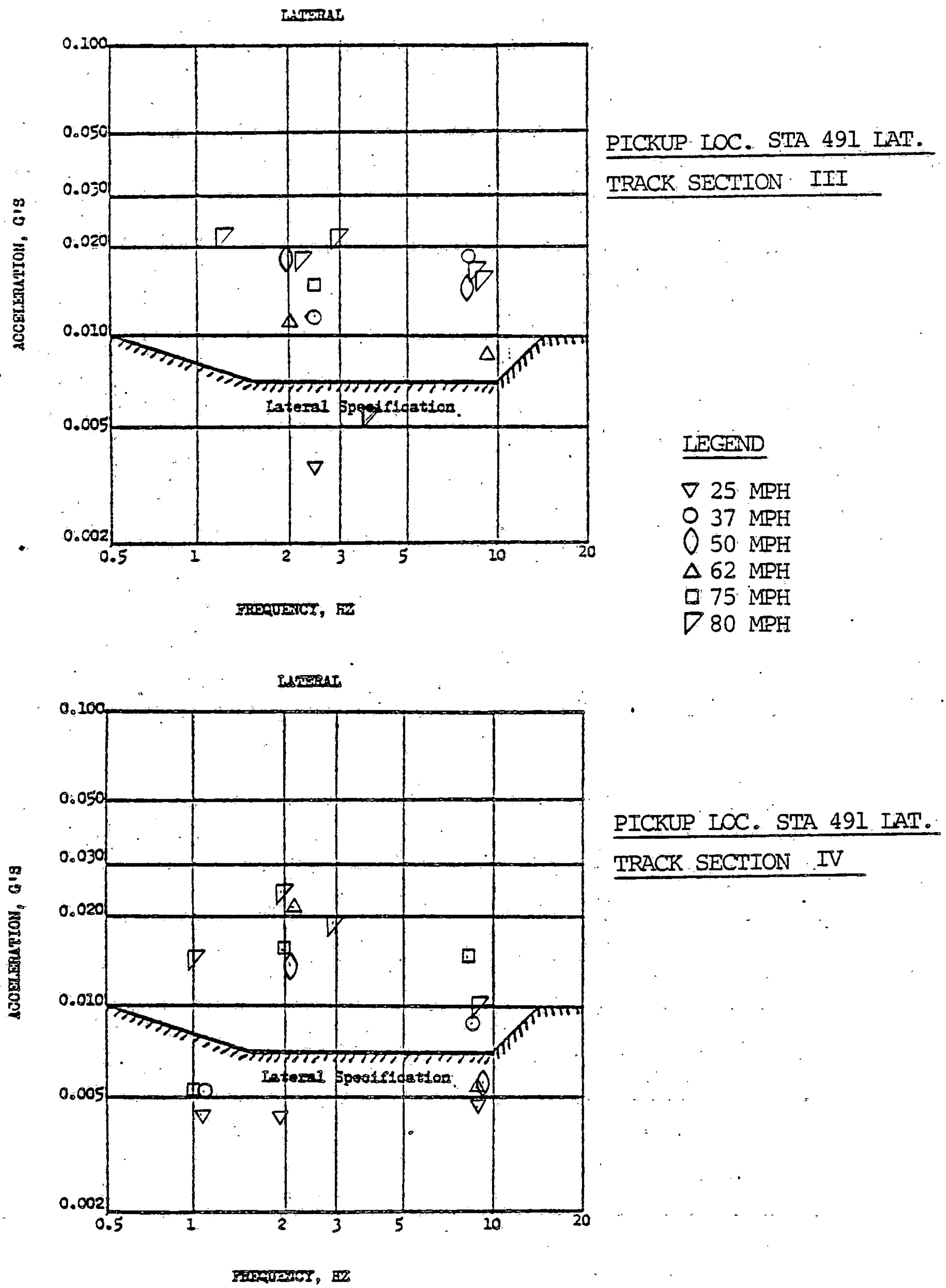


Figure 5–11. Ride Quality Comparison to Goals: Speed Effect at Station 491 Lateral

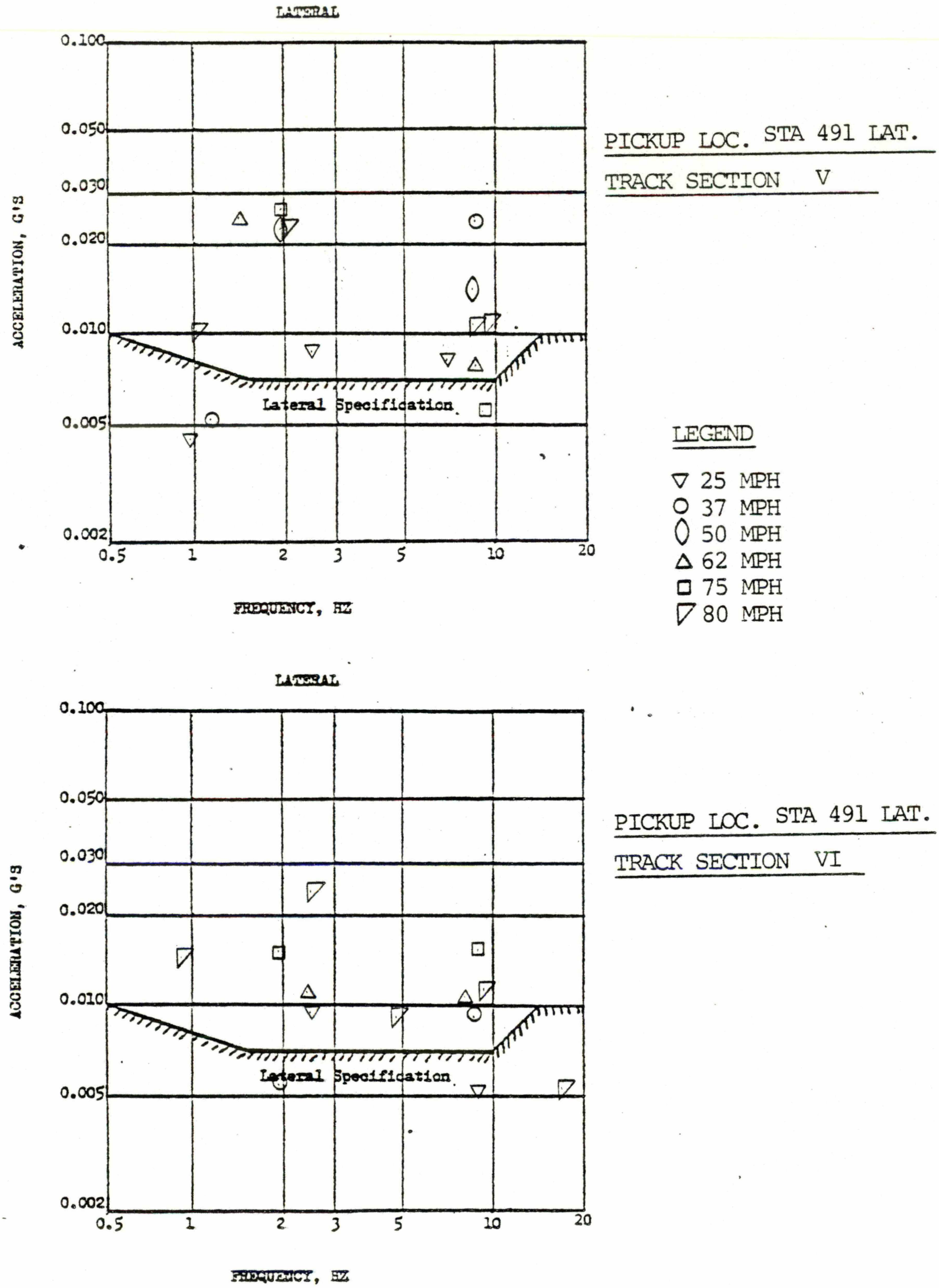


Figure 5–12. Ride Quality Comparison to Goals: Speed Effect at Station 491 Lateral

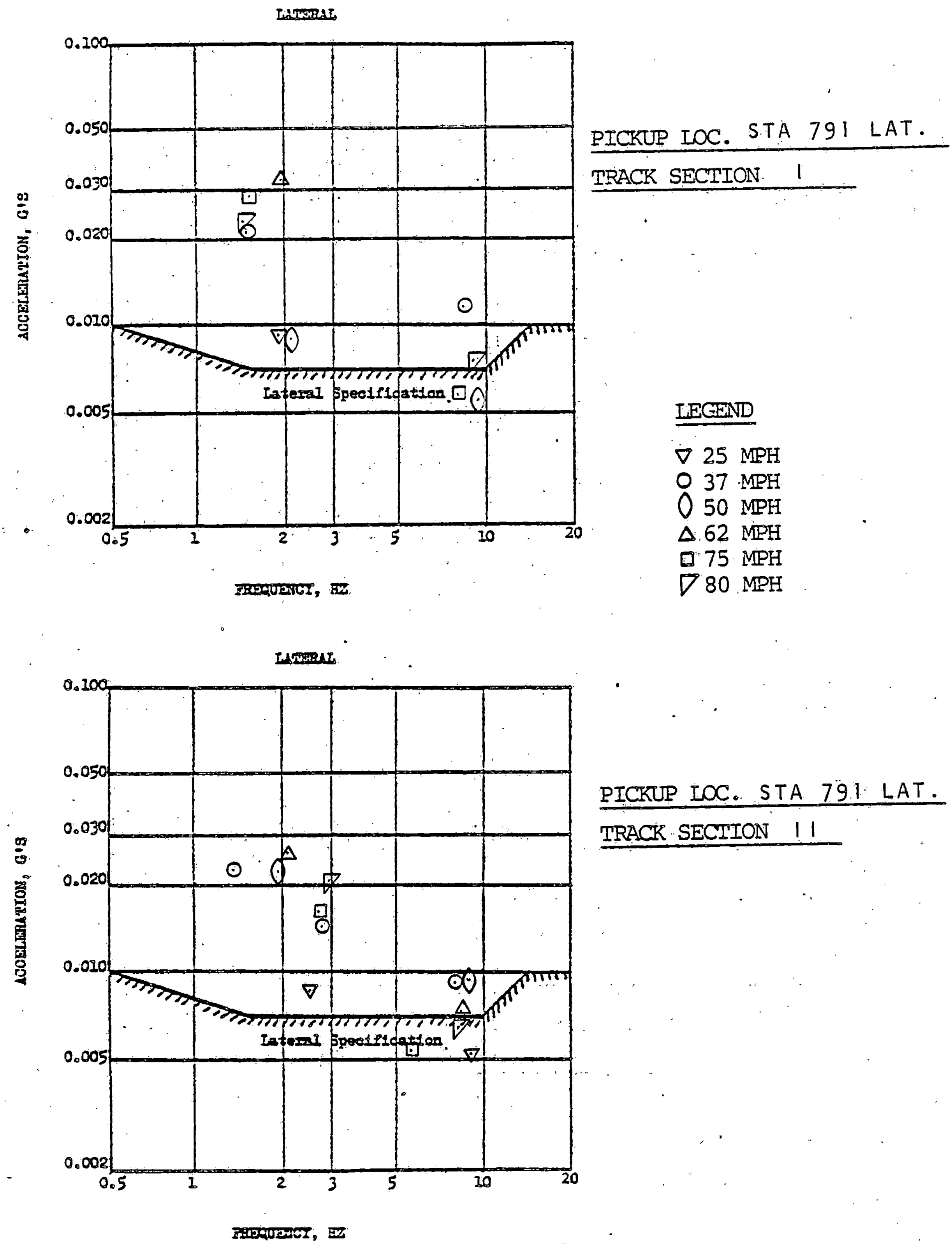


Figure 5–13. Ride Quality Comparison to Goals: Speed Effect at Station 791 Lateral

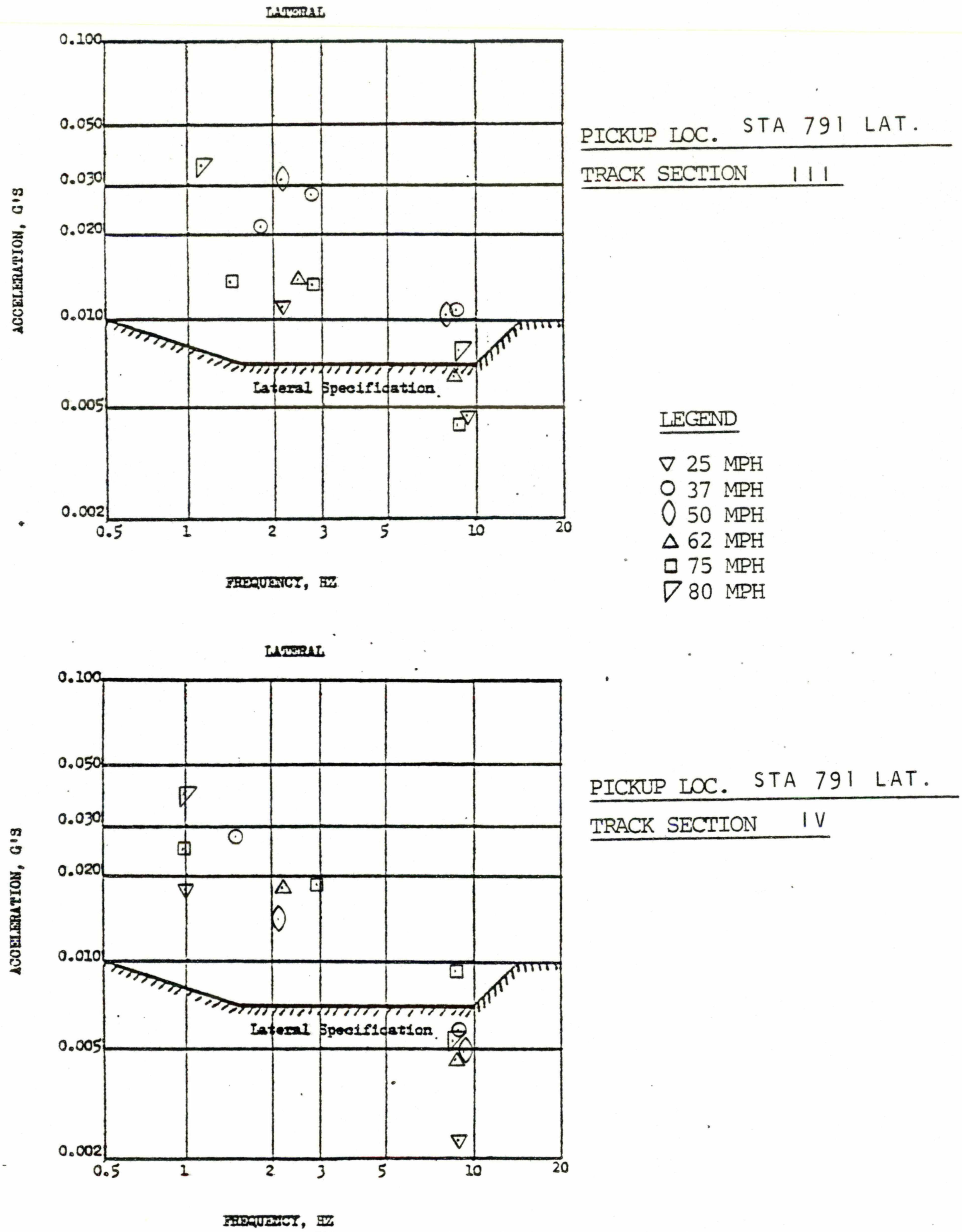
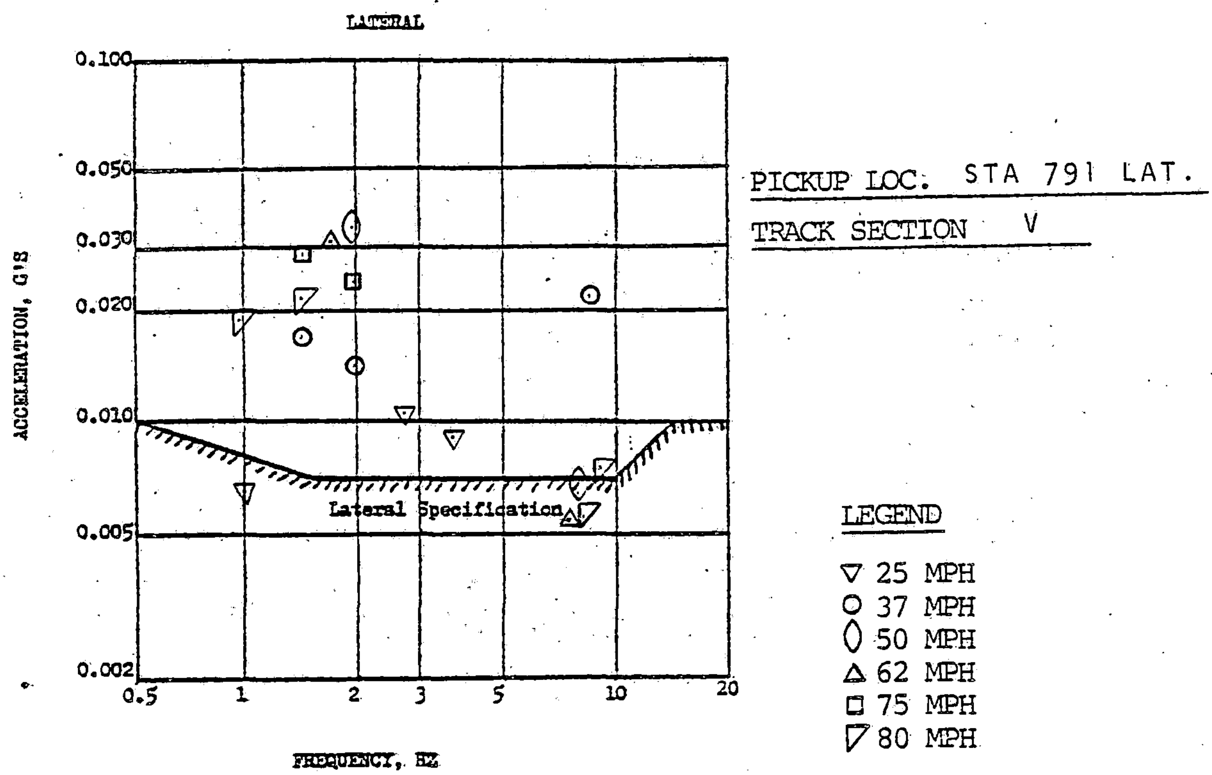


Figure 5–14. Ride Quality Comparison to Goals: Speed Effect at Station 791 Lateral



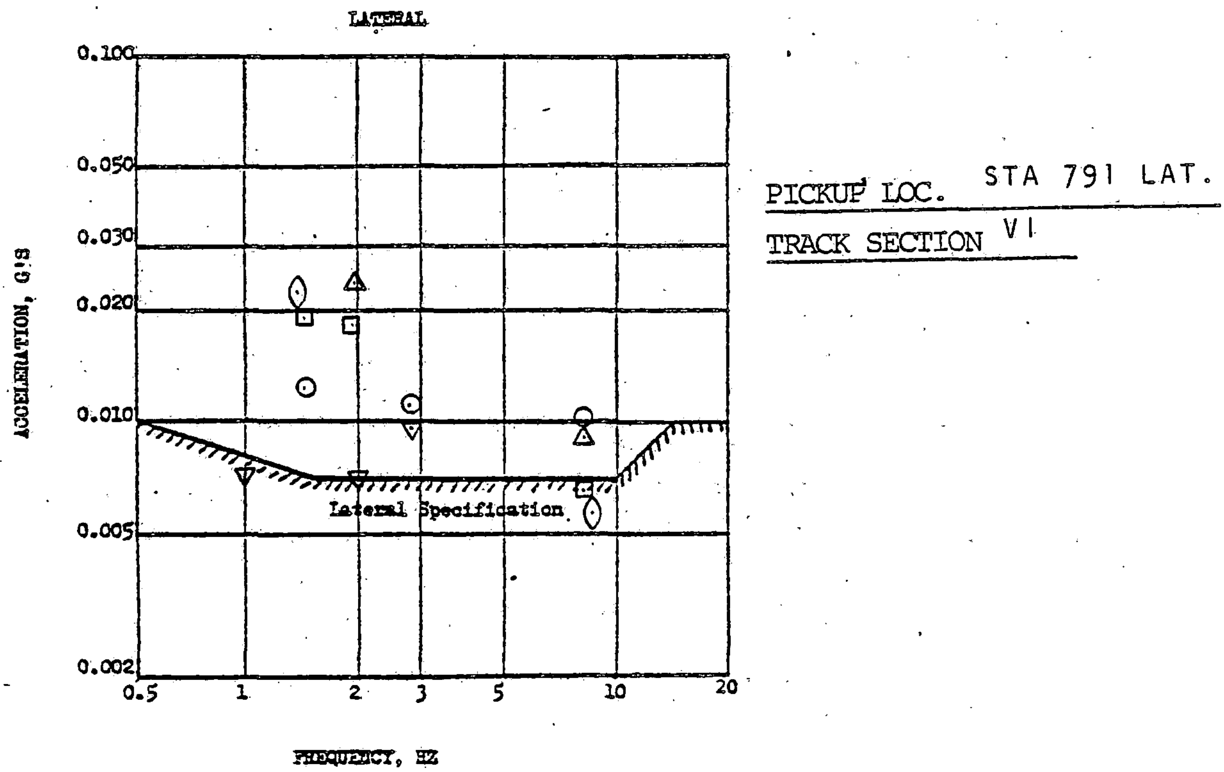


Figure 5–15. Ride Quality Comparison to Goals: Speed Effect at Station 791 Lateral

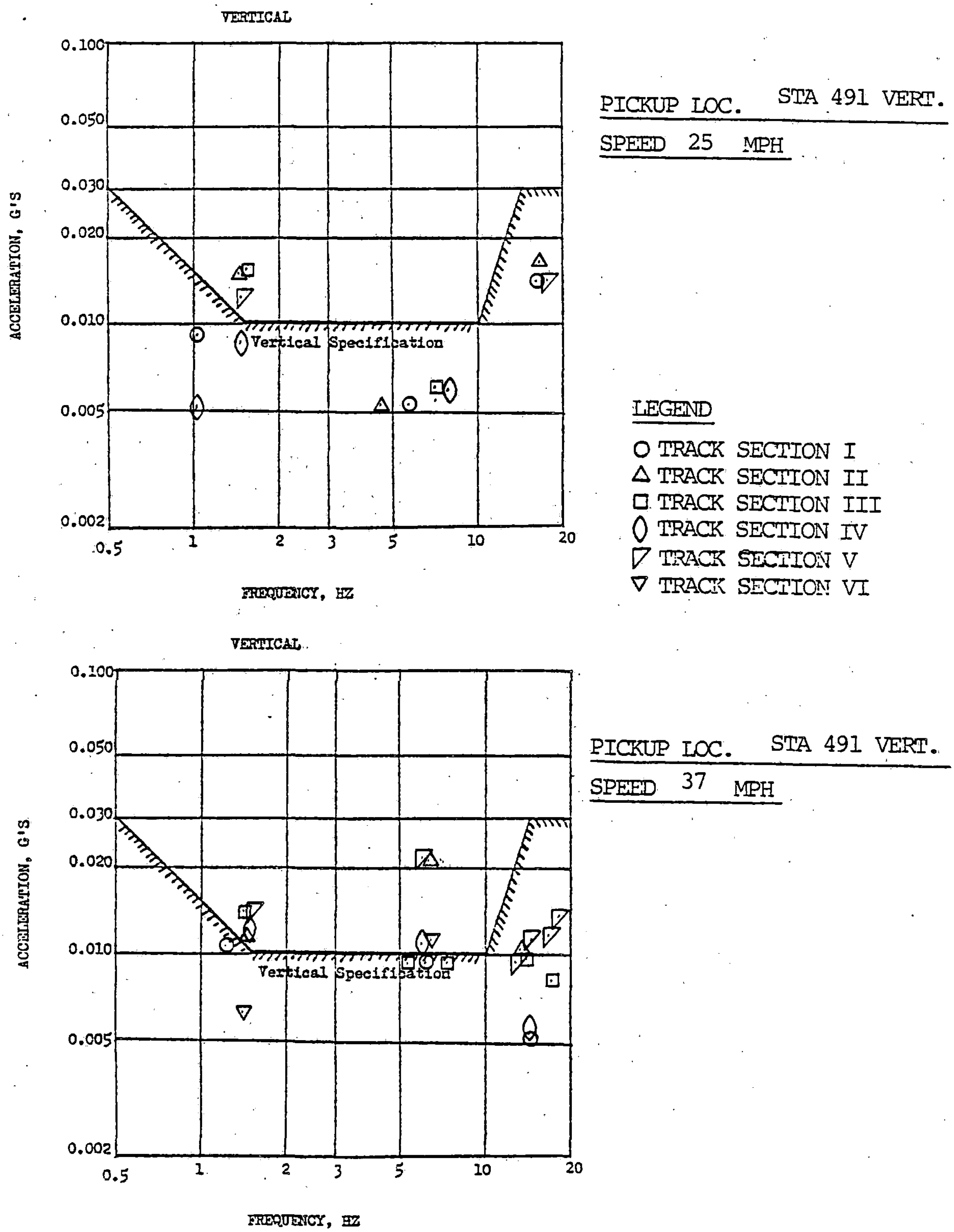
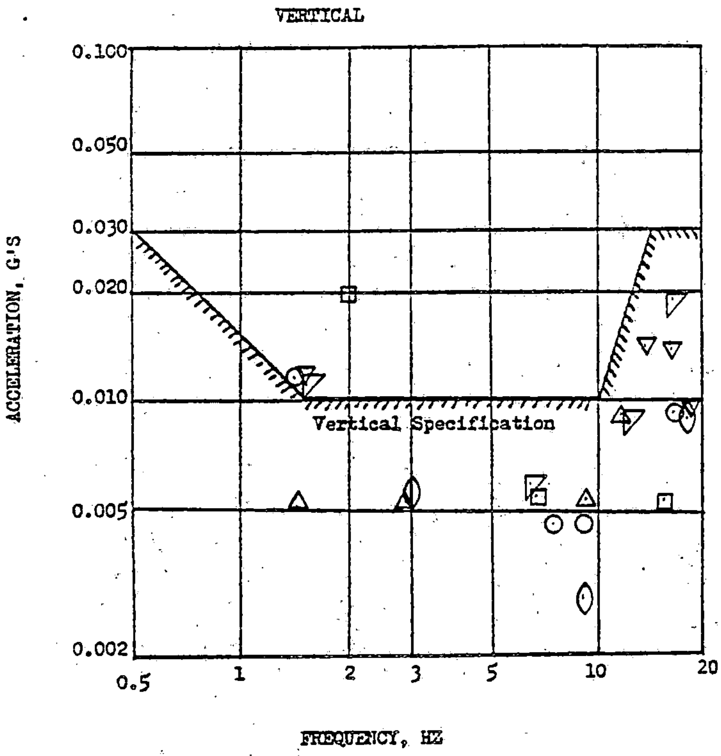


Figure 5–16. Ride Quality Comparison to Goals: Track Effect at Station 491 Vertical



PICKUP LOC. STA 491 VERT.

SPEED 50 MPH

LEGEND

○ TRACK SECTION I

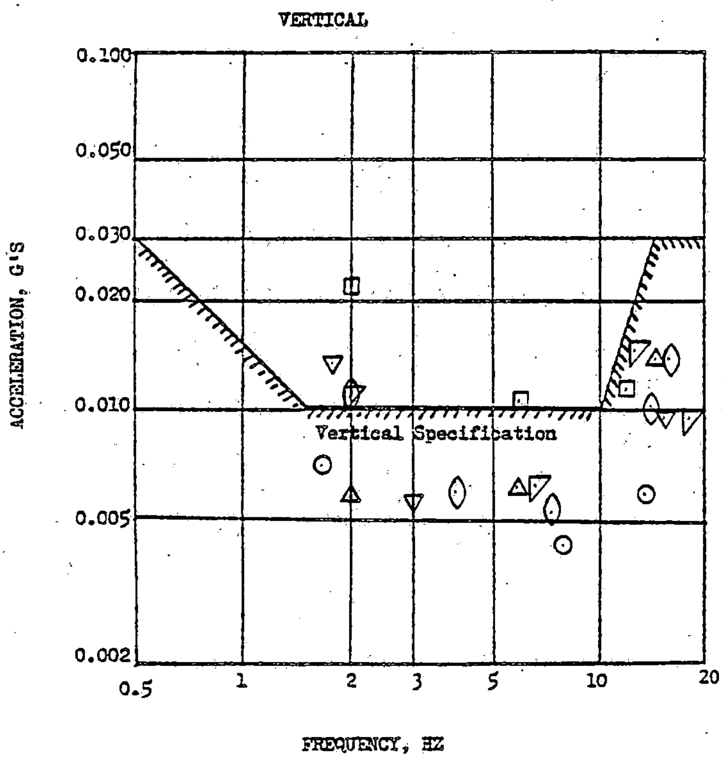
△ TRACK SECTION II

□ TRACK SECTION III

◊ TRACK SECTION IV

◸ TRACK SECTION V

▽ TRACK SECTION VI



PICKUP LOC. STA 491 VERT.

SPEED 62 MPH

Figure 5–17. Ride Quality Comparison to Goals: Track Effect at Station 491 Vertical

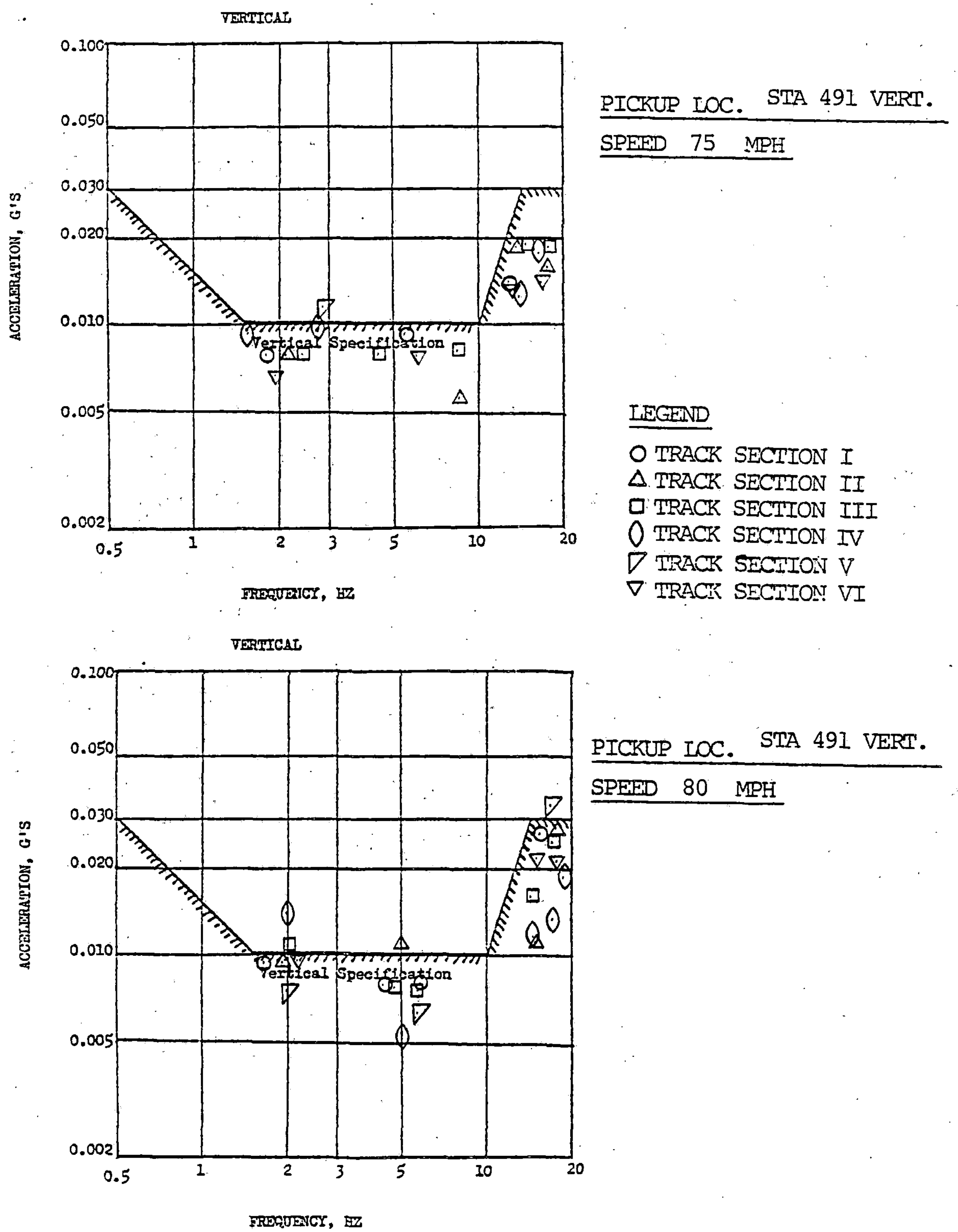


Figure 5–18. Ride Quality Comparison to Goals: Track Effect at Station 491 Vertical

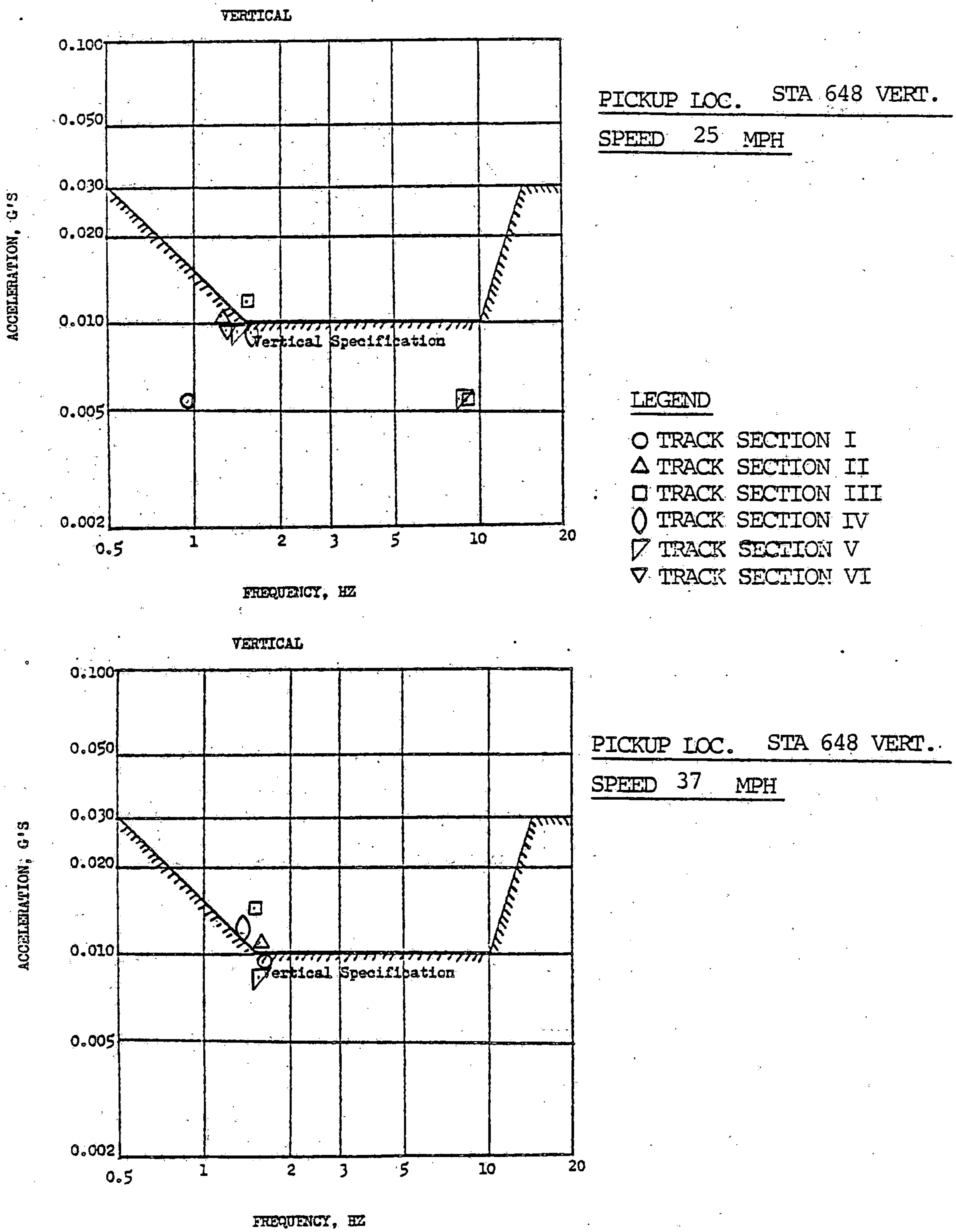


Figure 5–19. Ride Quality Comparison to Goals: Track Effect at Station 648 Vertical

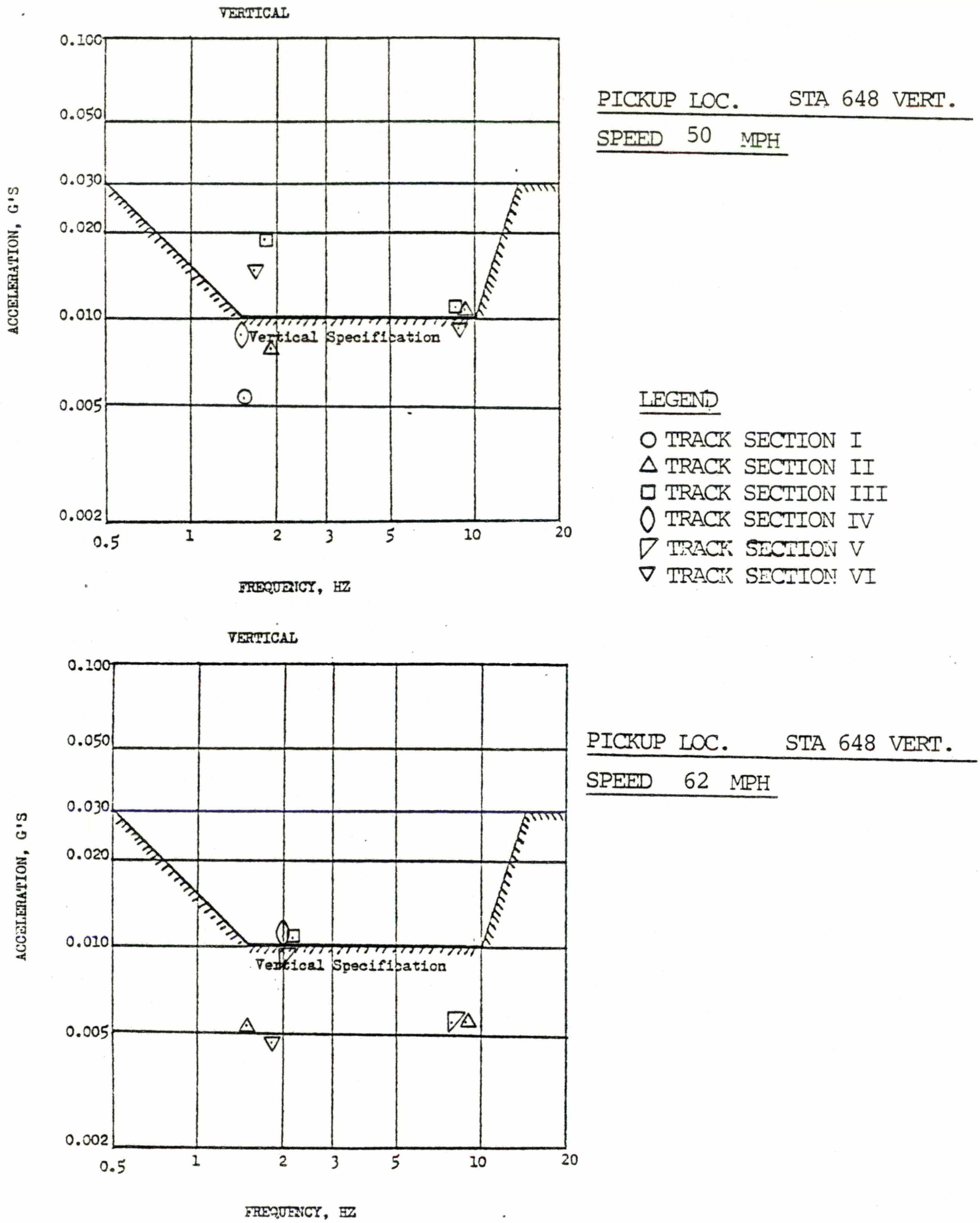


Figure 5–20. Ride Quality Comparison to Goals: Track Effect at Station 648 Vertical

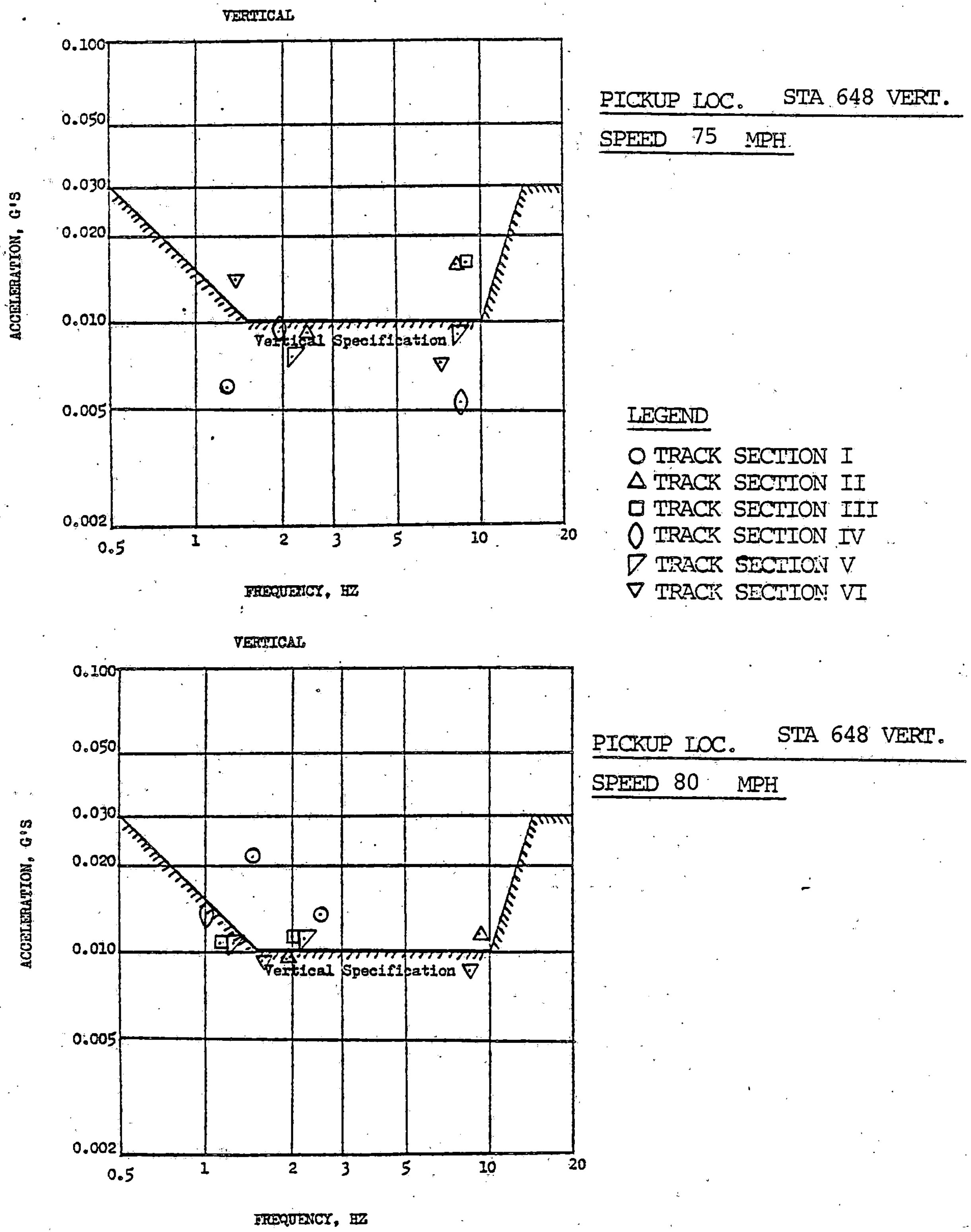


Figure 5–21. Ride Quality Comparison to Goals: Track Effect at Station 648 Vertical

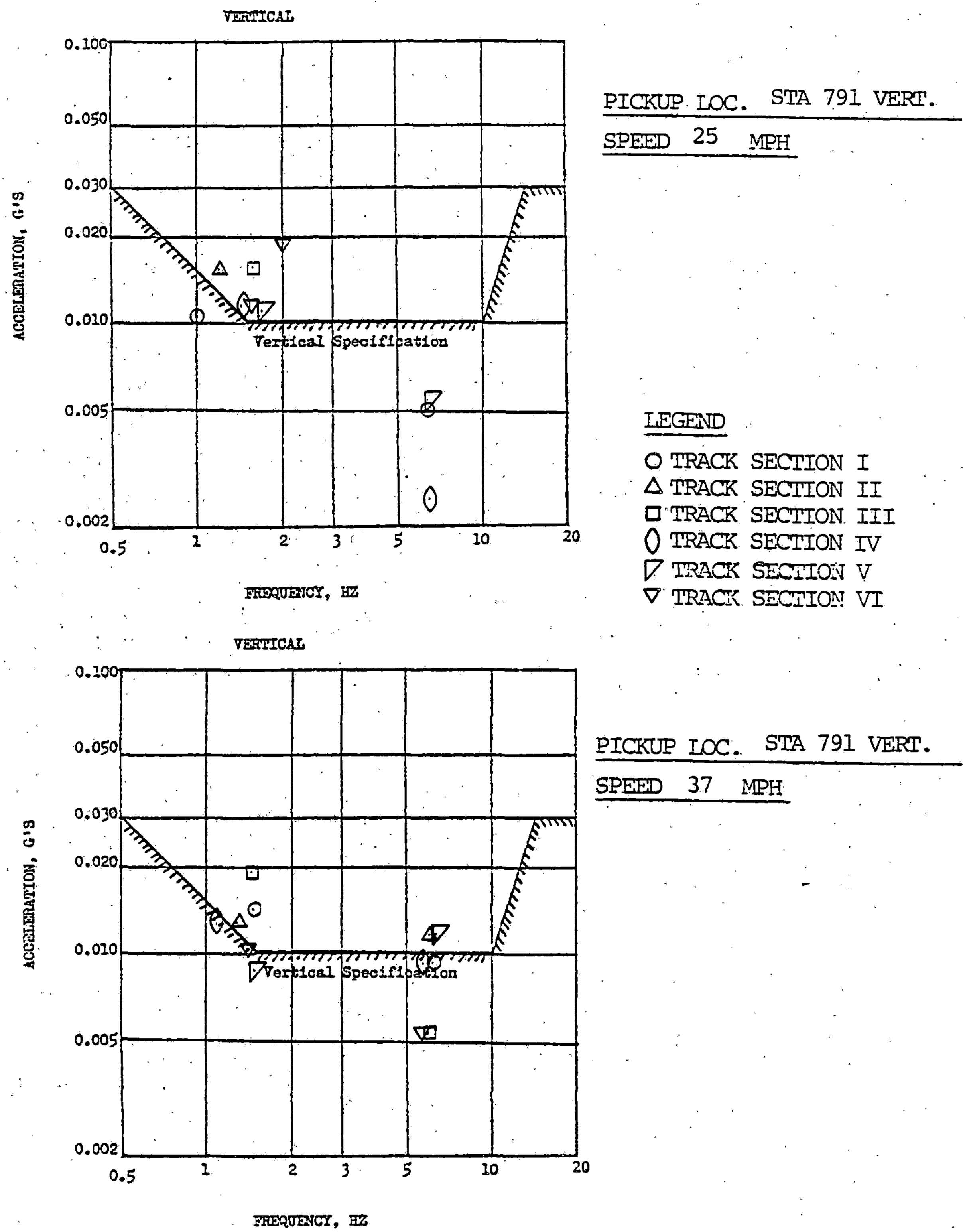


Figure 5–22. Ride Quality Comparison to Goals: Track Effect at Station 791 Vertical

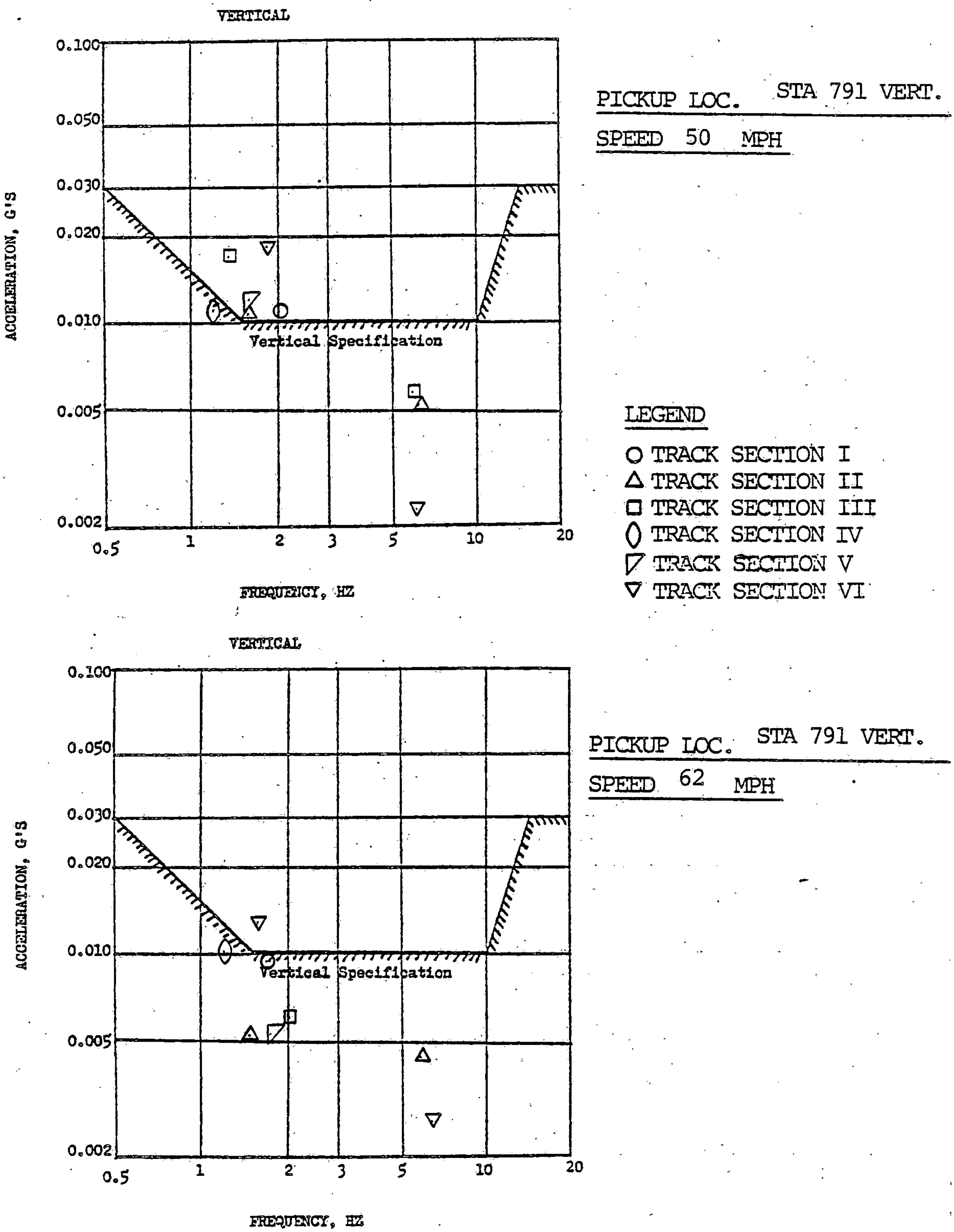
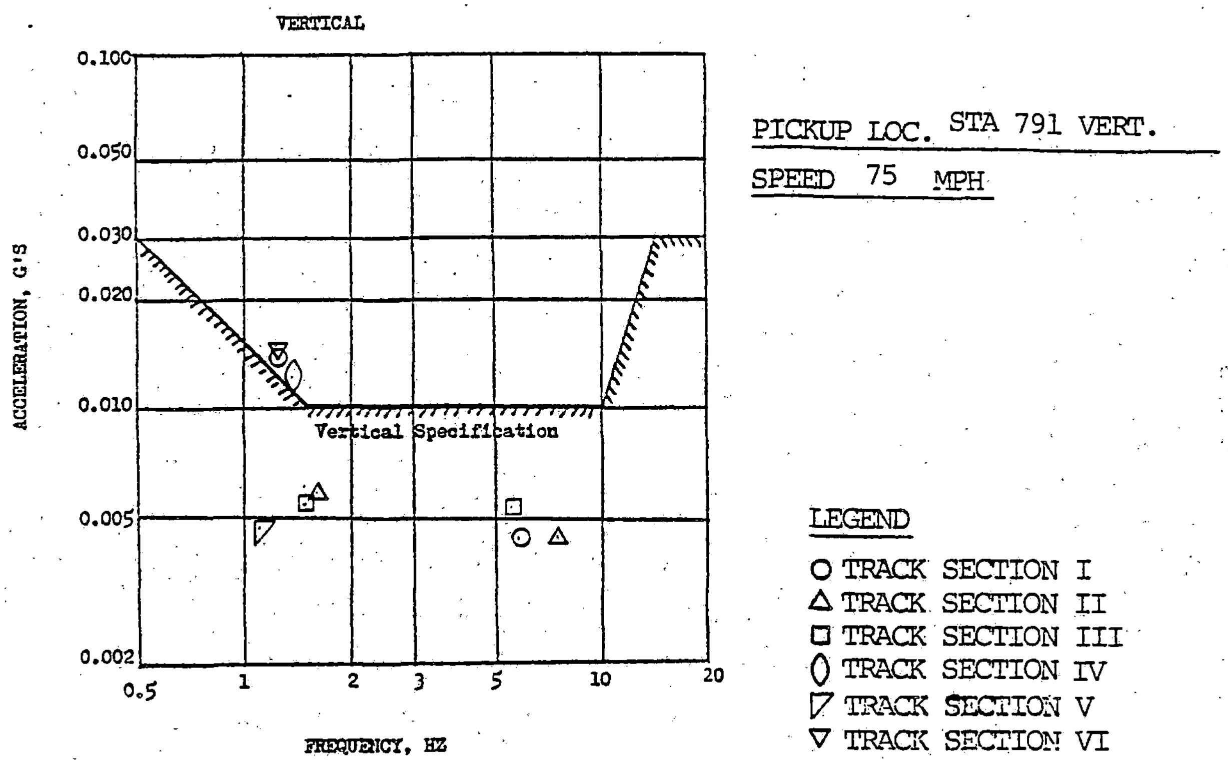


Figure 5–23. Ride Quality Comparison to Goals: Track Effect at Station 791 Vertical



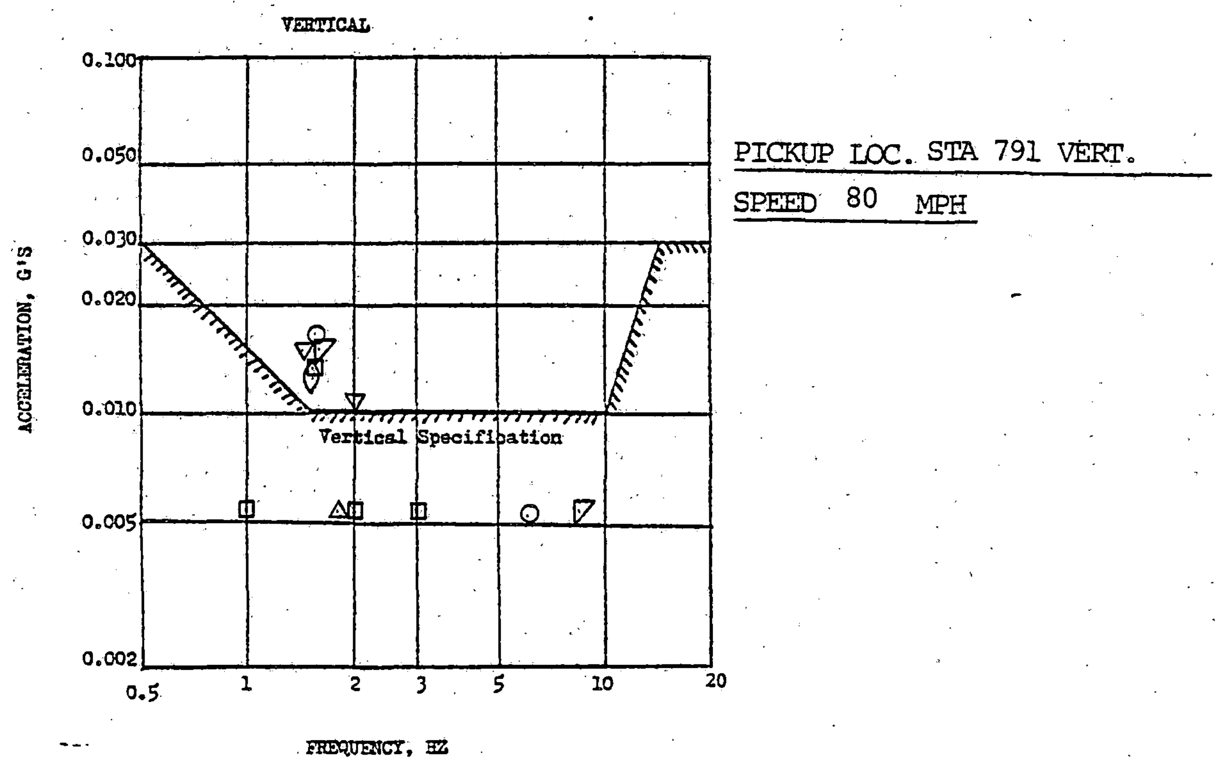


Figure 5–24. Ride Quality Comparison to Goals: Track Effect at Station 791 Vertical

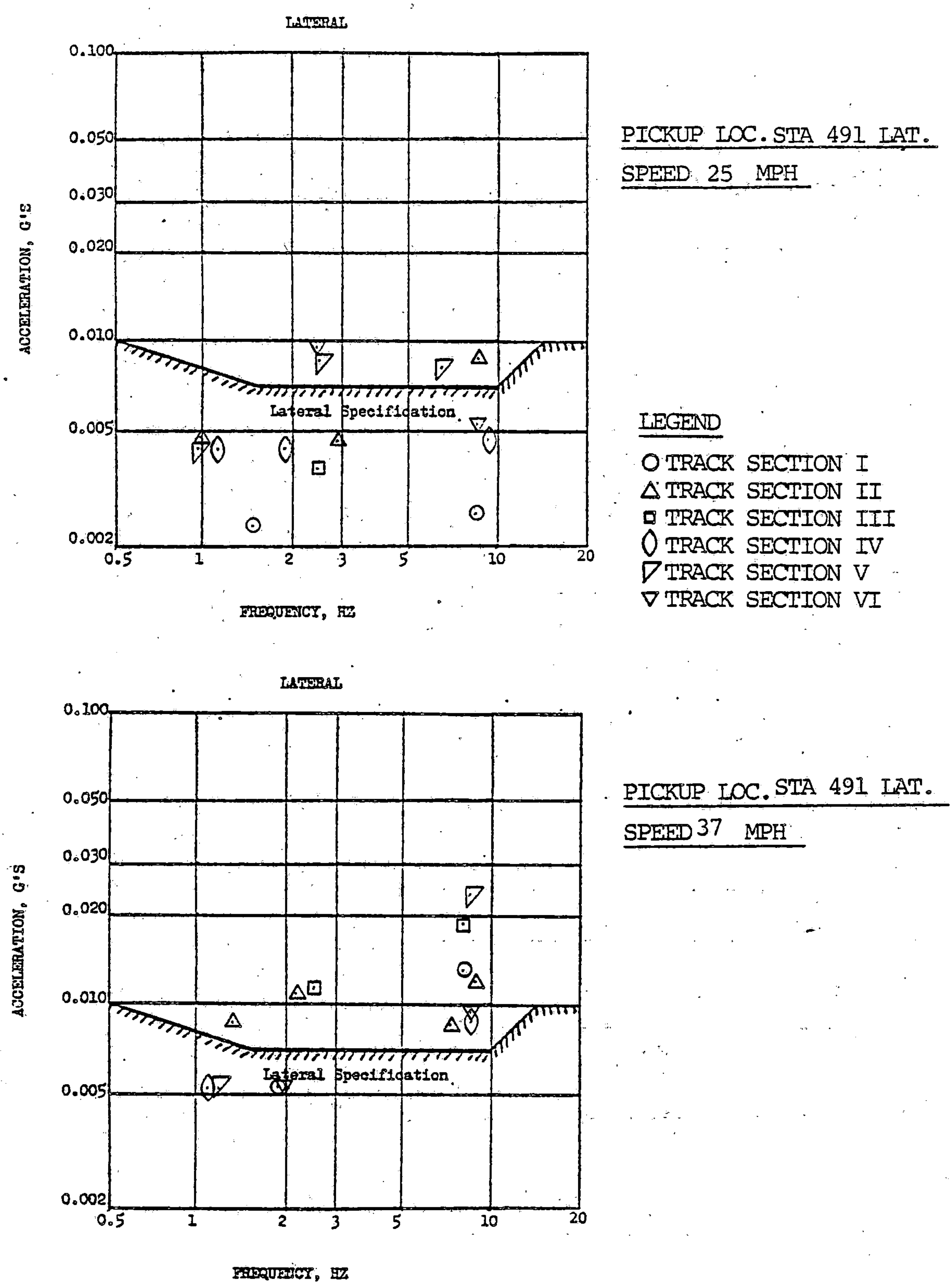
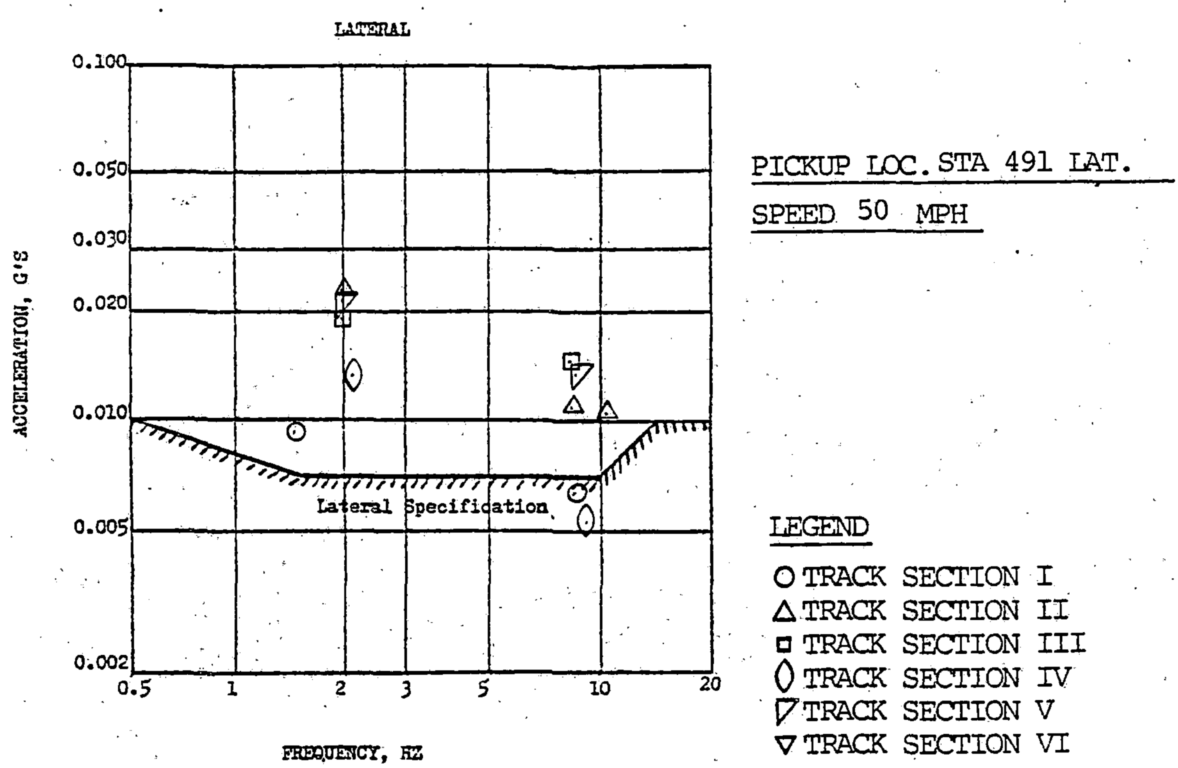


Figure 5–25. Ride Quality Comparison to Goals: Track Effect at Station 491 Lateral



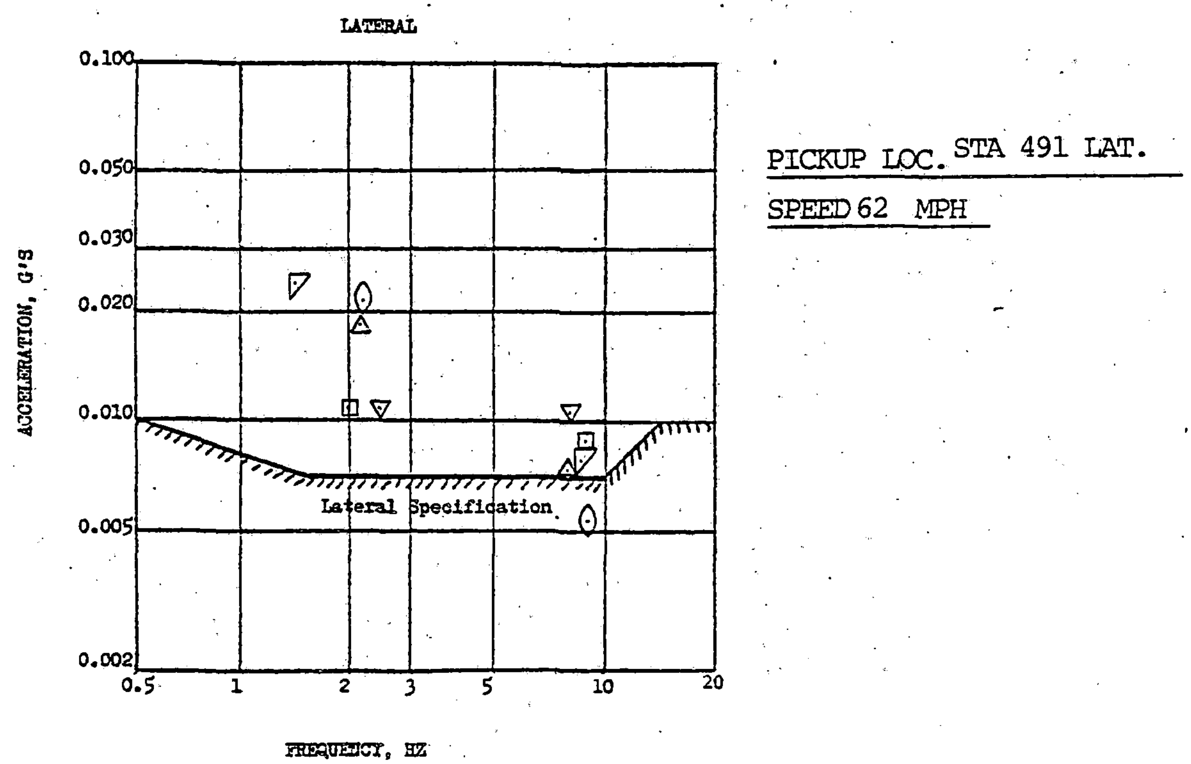
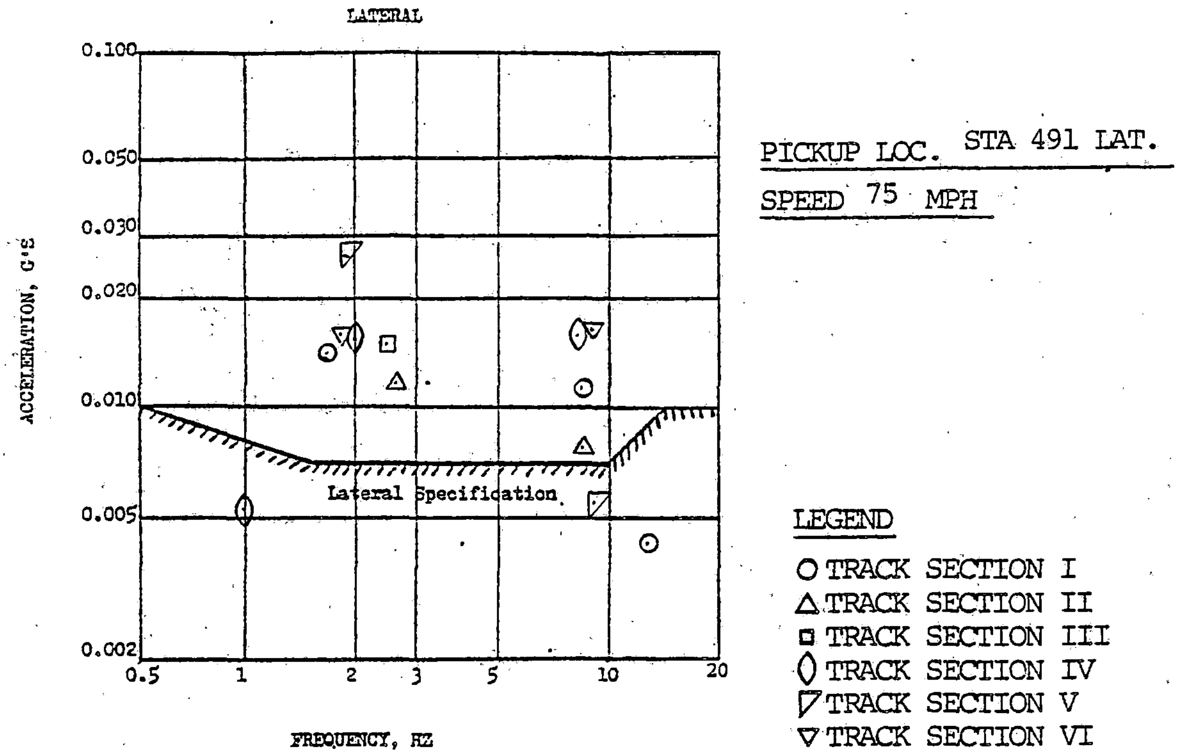


Figure 5–26. Ride Quality Comparison to Goals: Track Effect at Station 491 Lateral



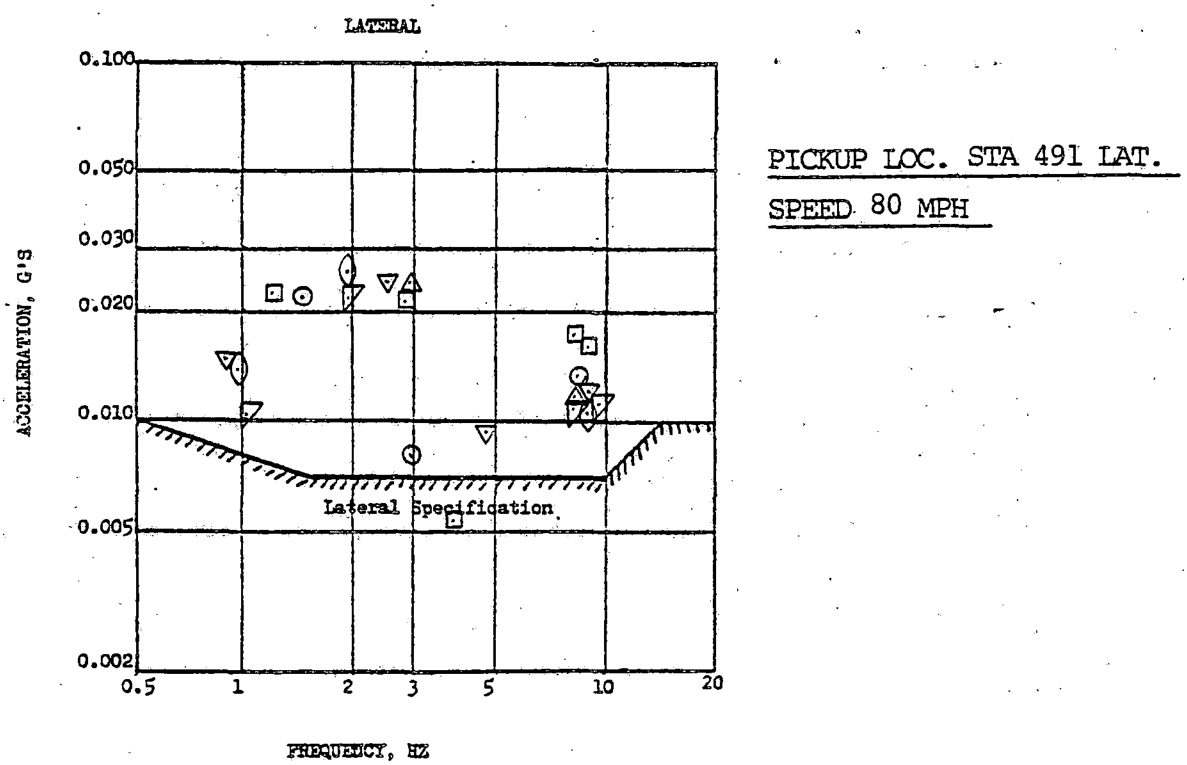
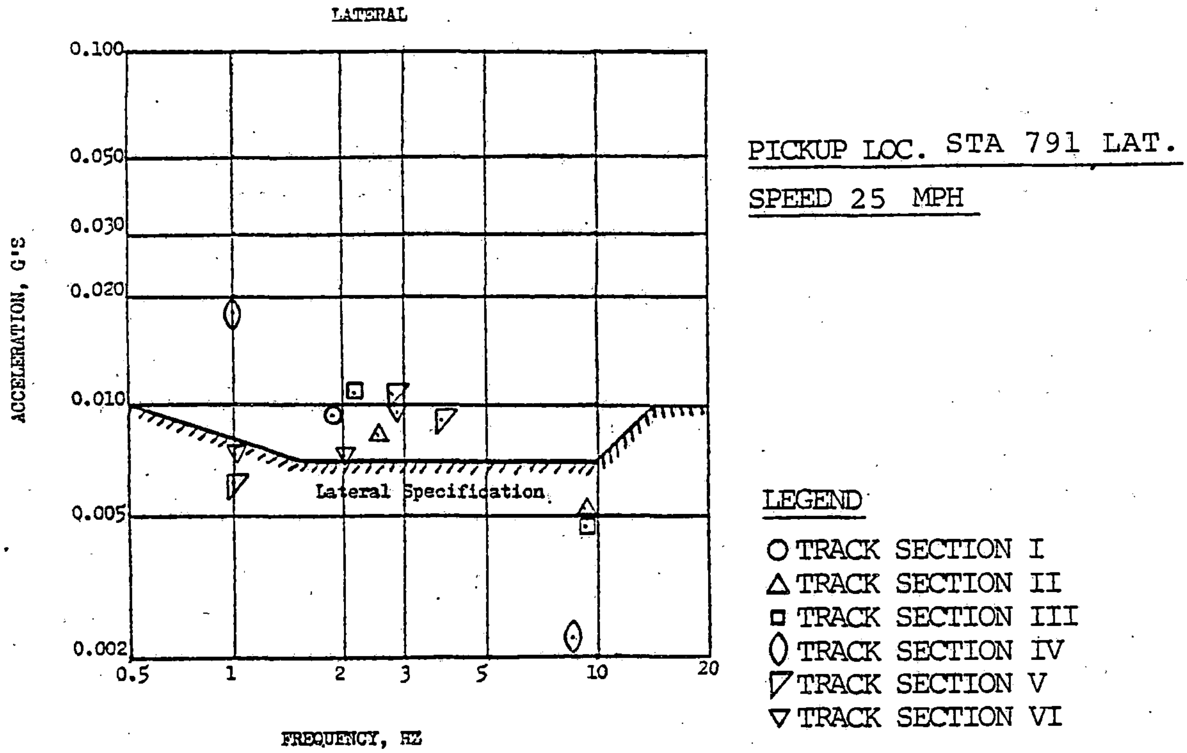


Figure 5–27. Ride Quality Comparison to Goals: Track Effect at Station 491 Lateral



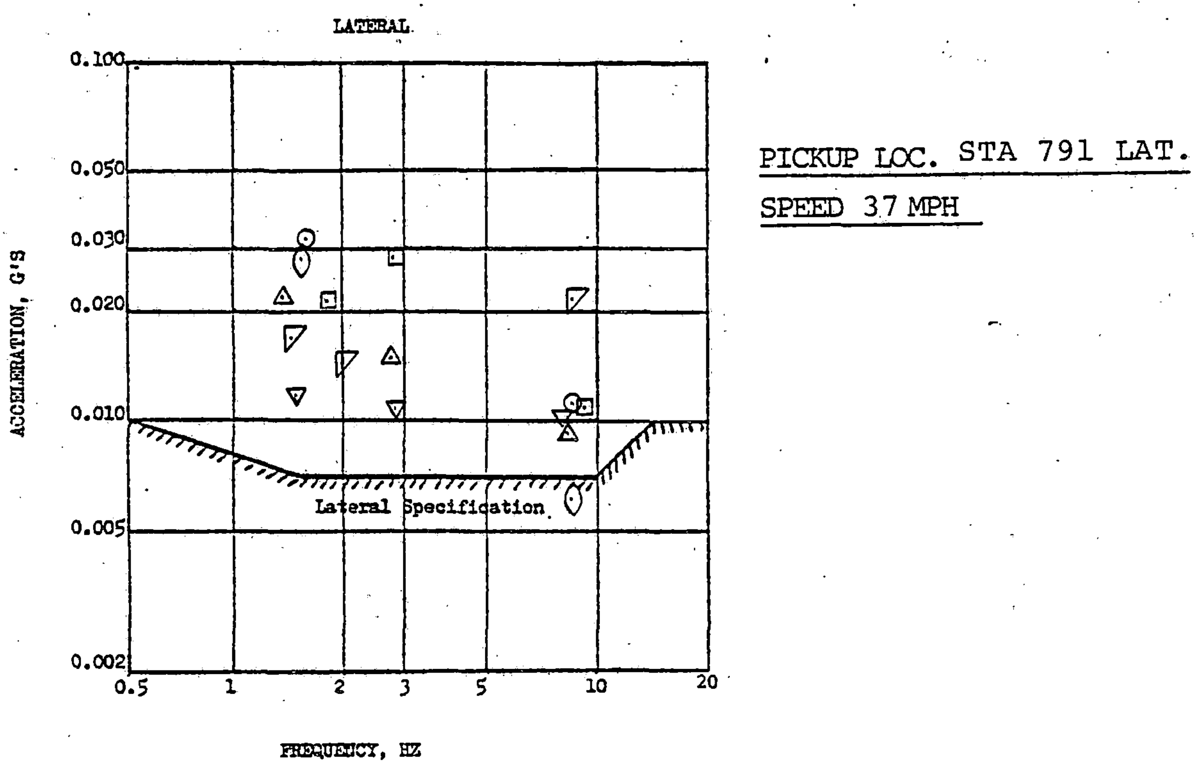


Figure 5–28. Ride Quality Comparison to Goals: Track Effect at Station 791 Lateral

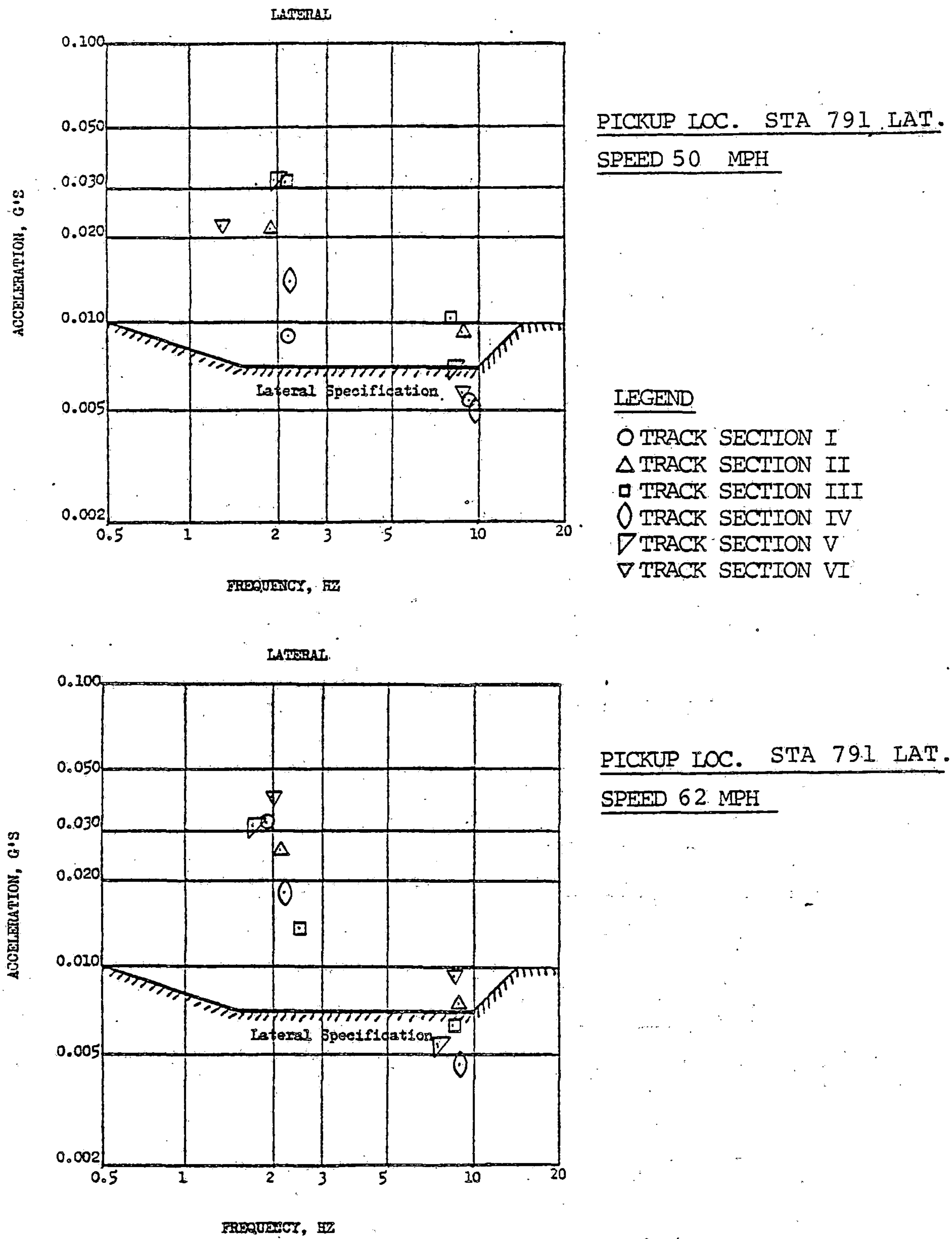
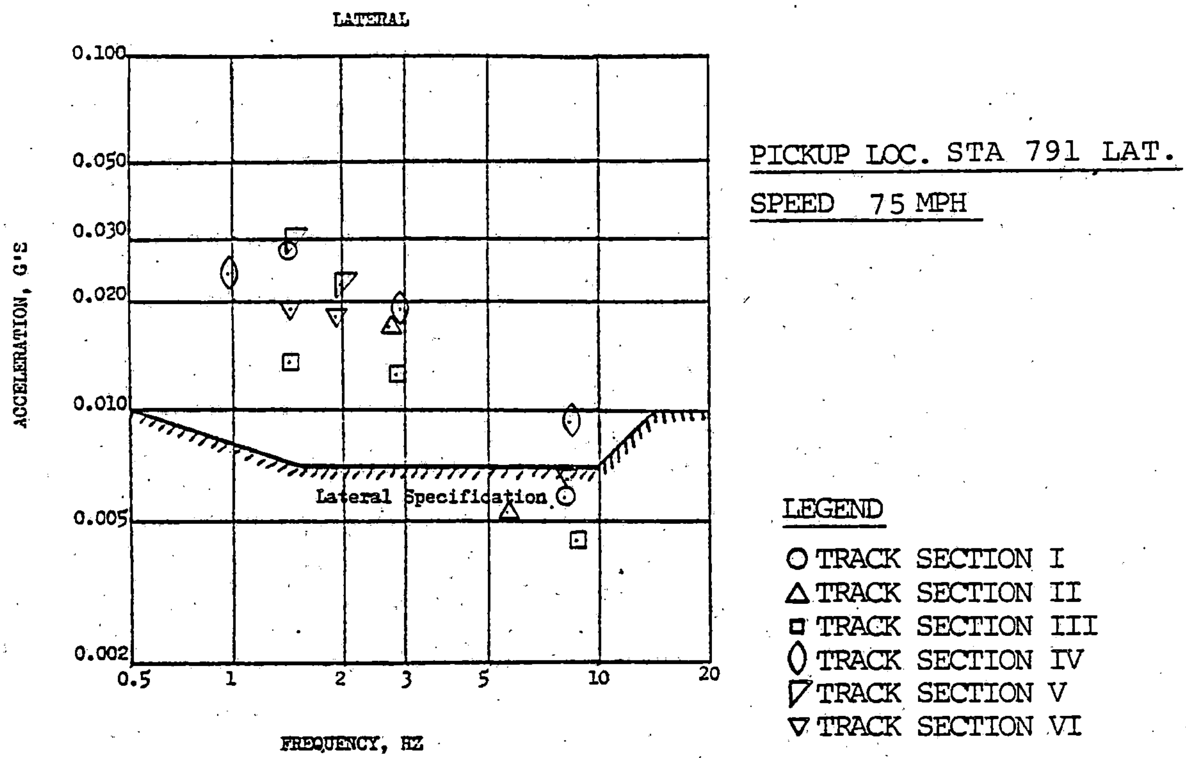


Figure 5–29. Ride Quality Comparison to Goals: Track Effect at Station 791 Lateral



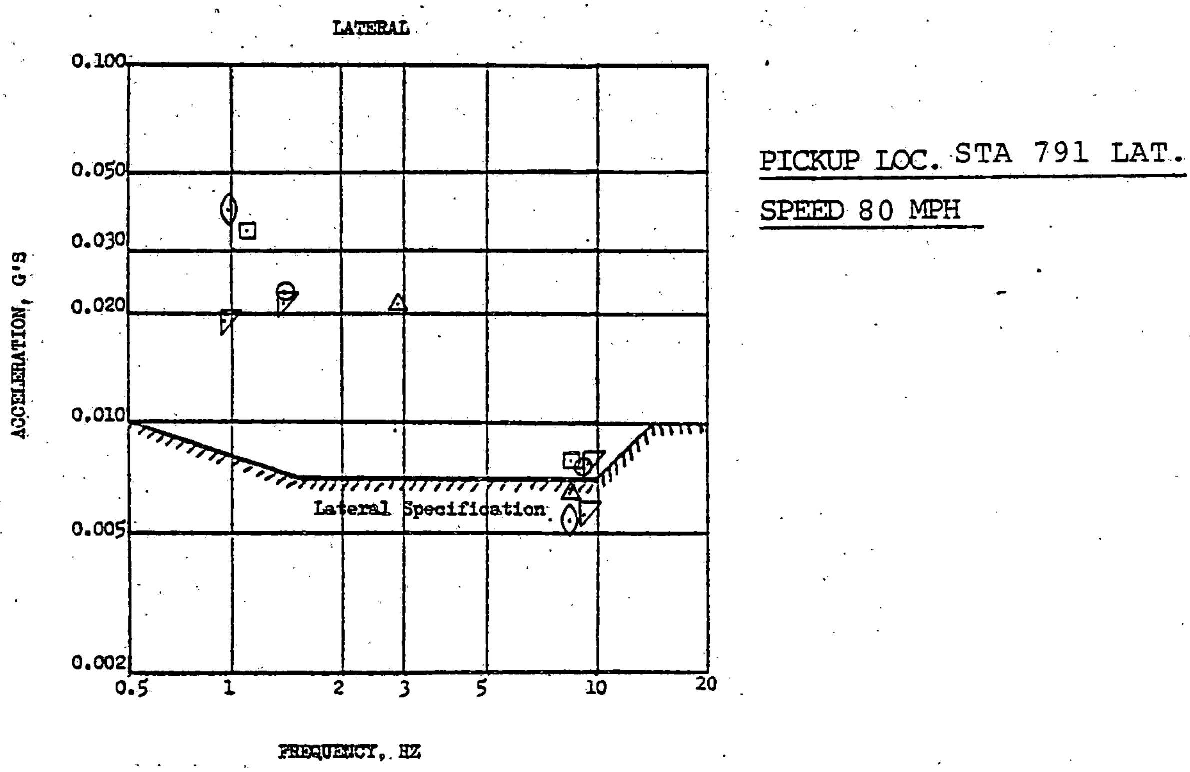


Figure 5–30. Ride Quality Comparison to Goals: Track Effect at Station 791 Lateral

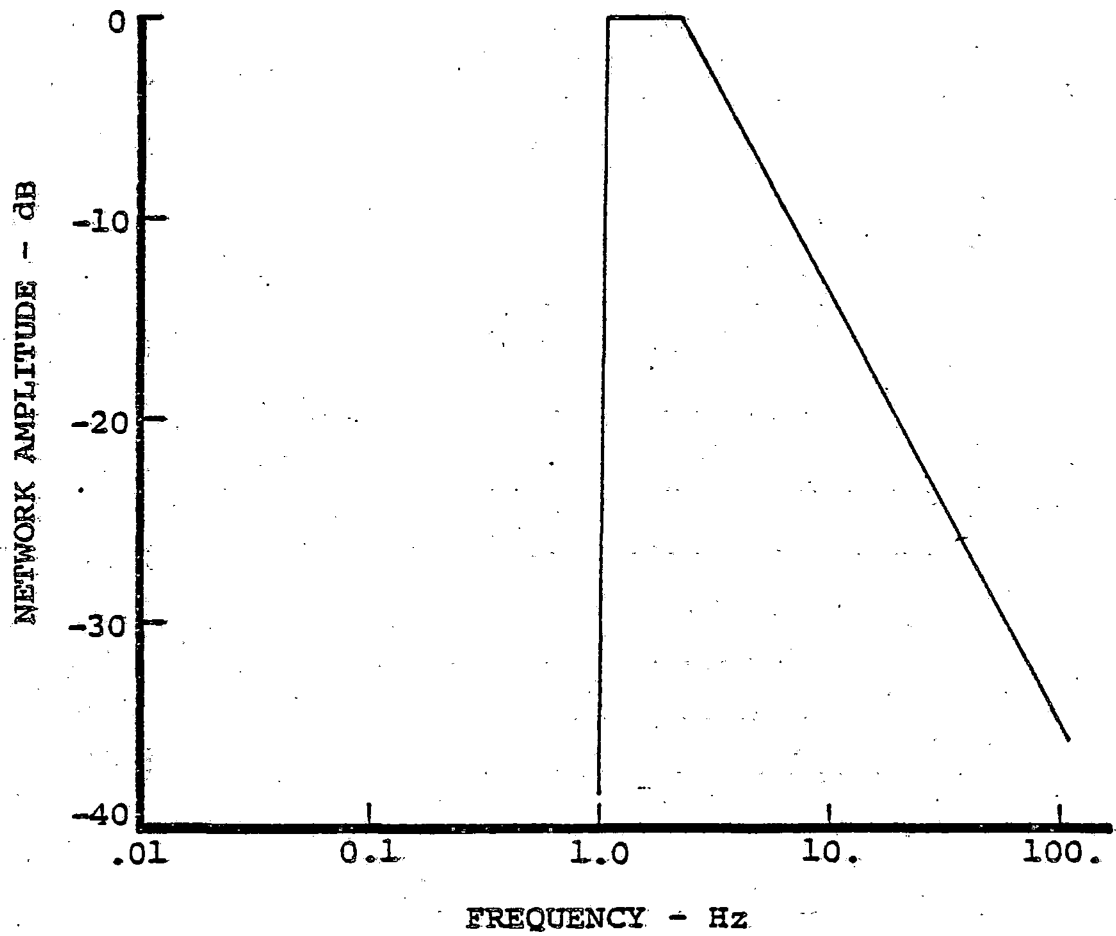


Figure 5–31. Shaper for Horizontal Signal Weighting

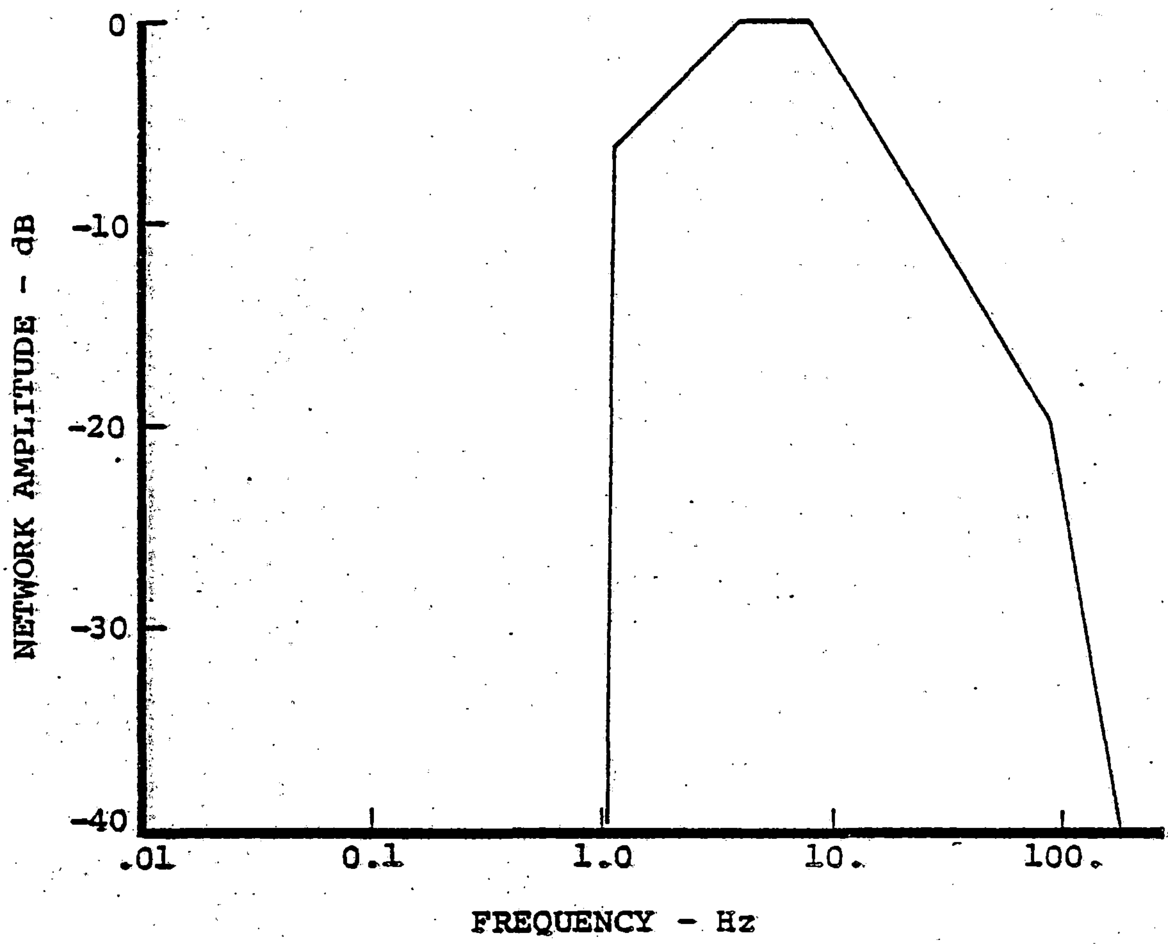


Figure 5–32. Shaper for Vertical Signal Weighting

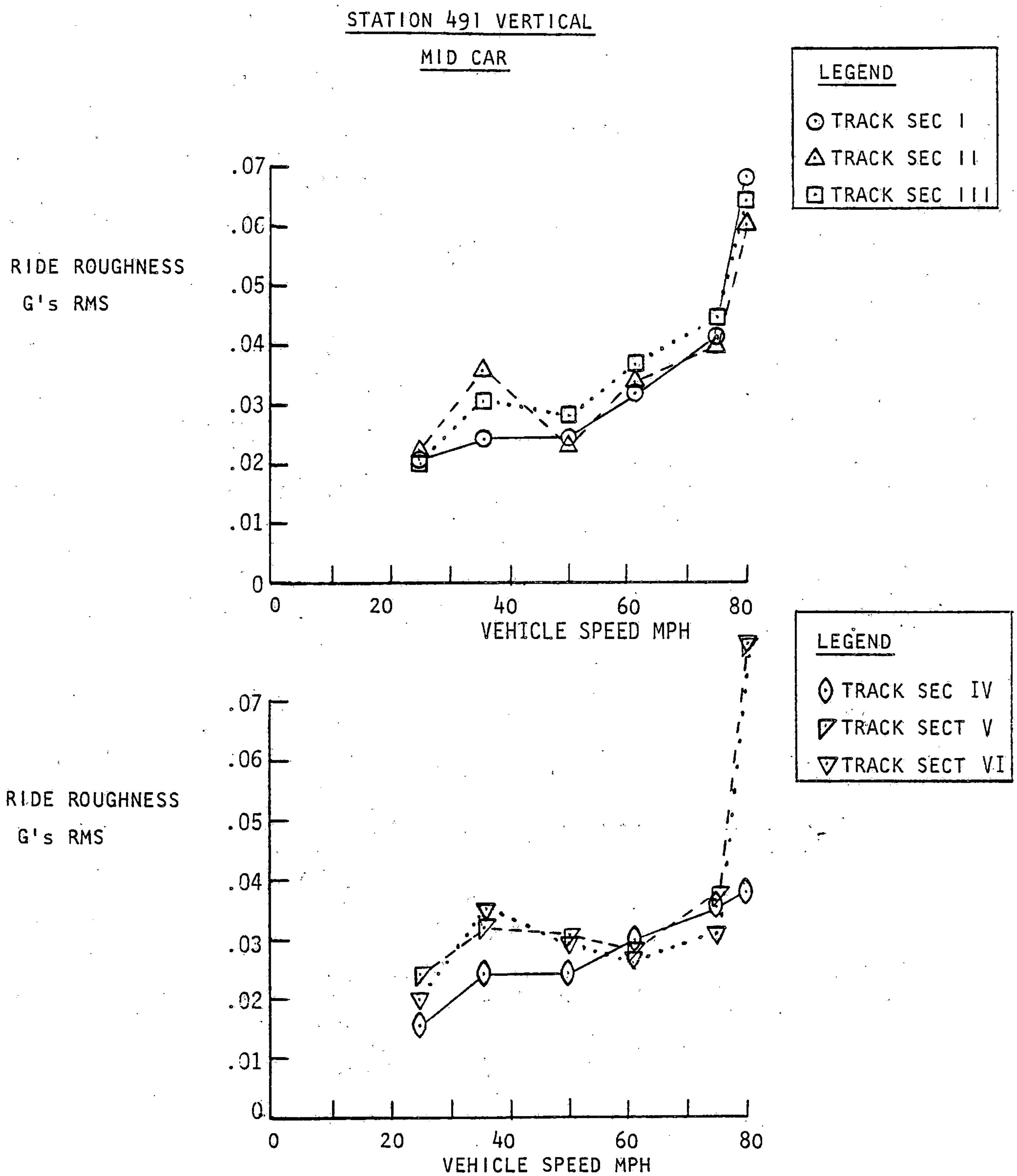
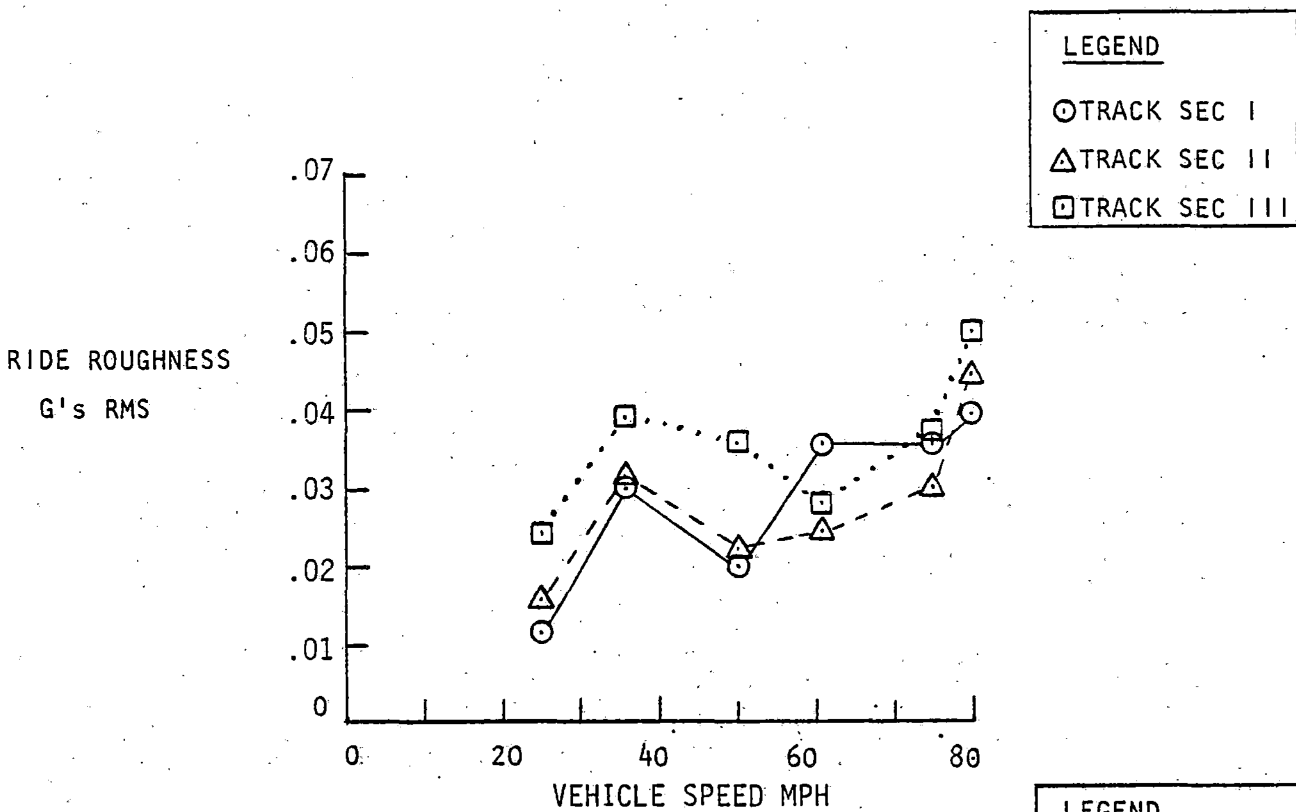


Figure 5–33. Effect of Vehicle Speed on Vertical Ride Roughness

STATION 648 VERTICAL



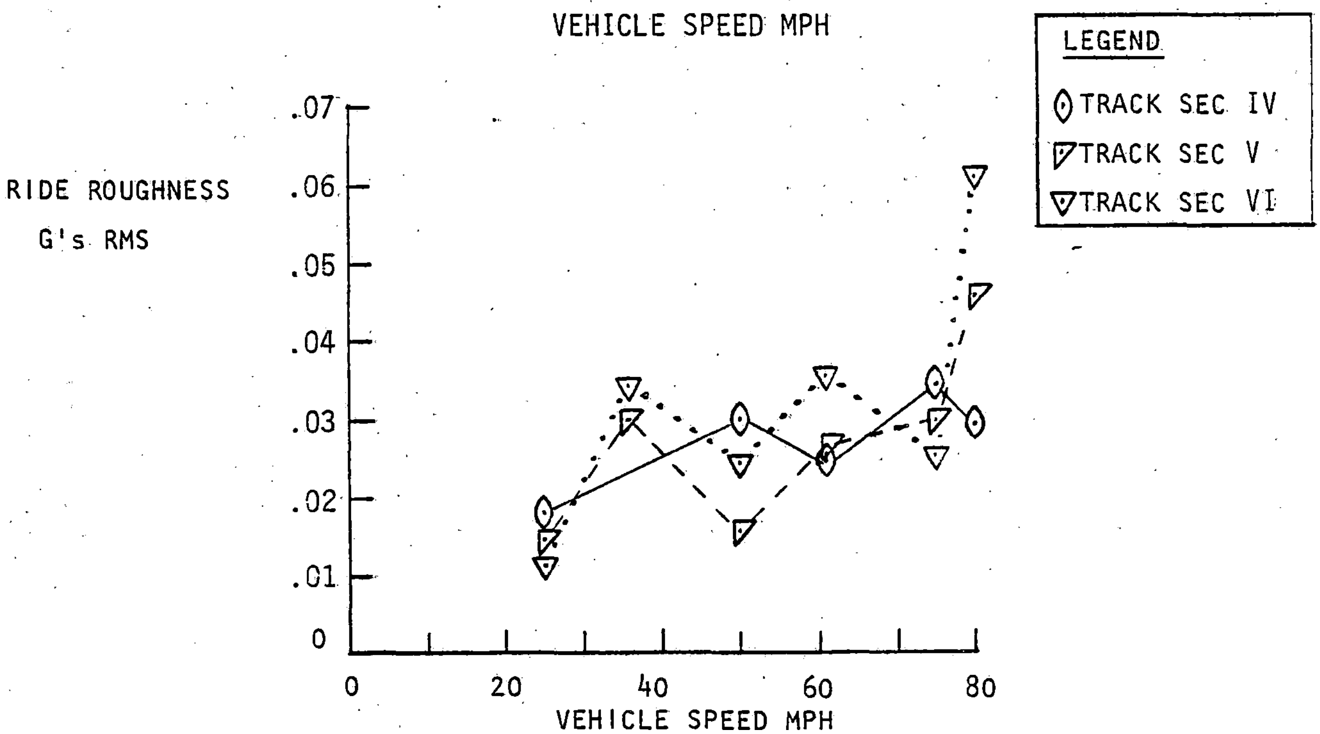


Figure 5–34. Effect of Vehicle Speed on Vertical Ride Roughness

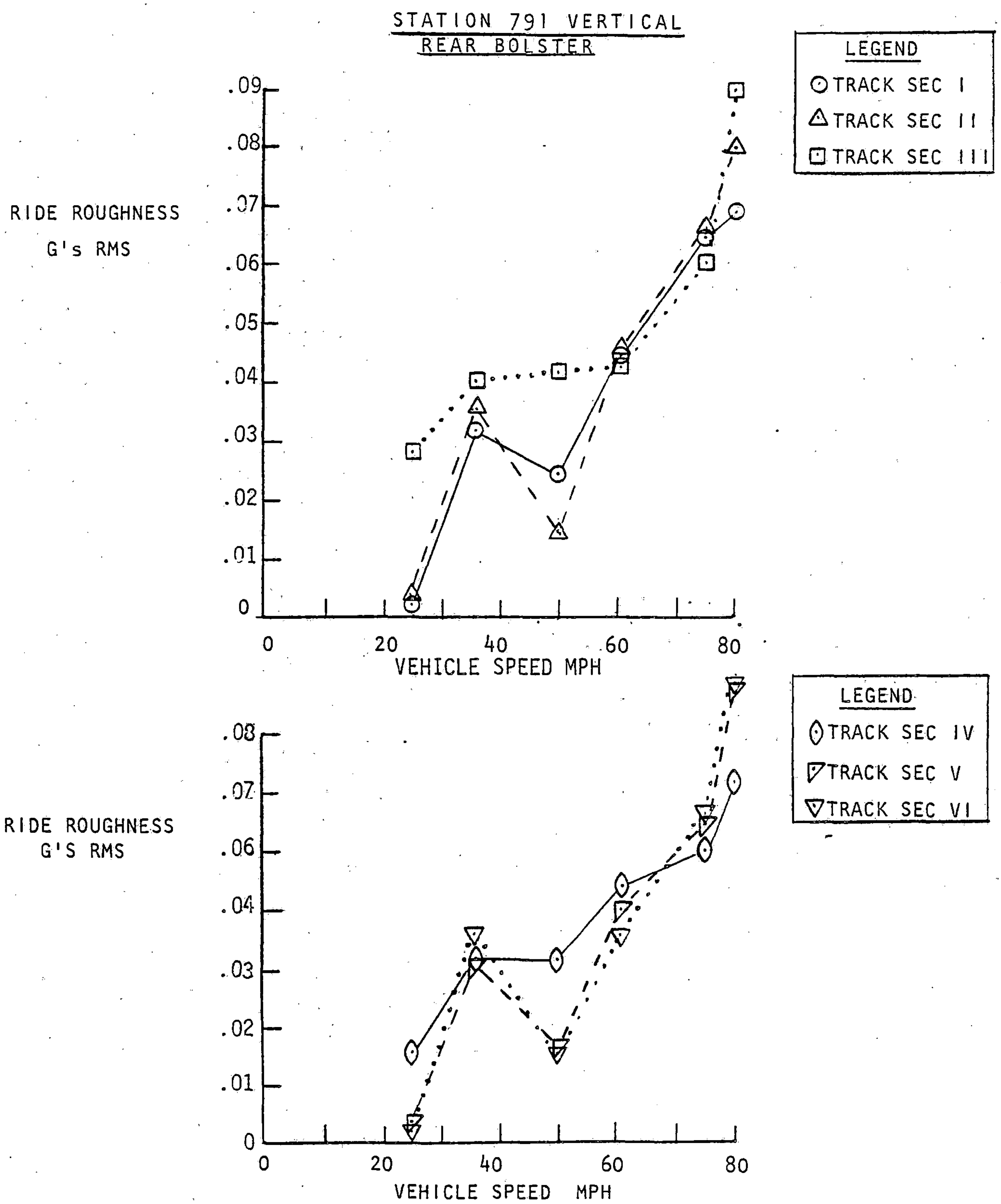


Figure 5–35. Effect of Vehicle Speed on Vertical Ride Roughness

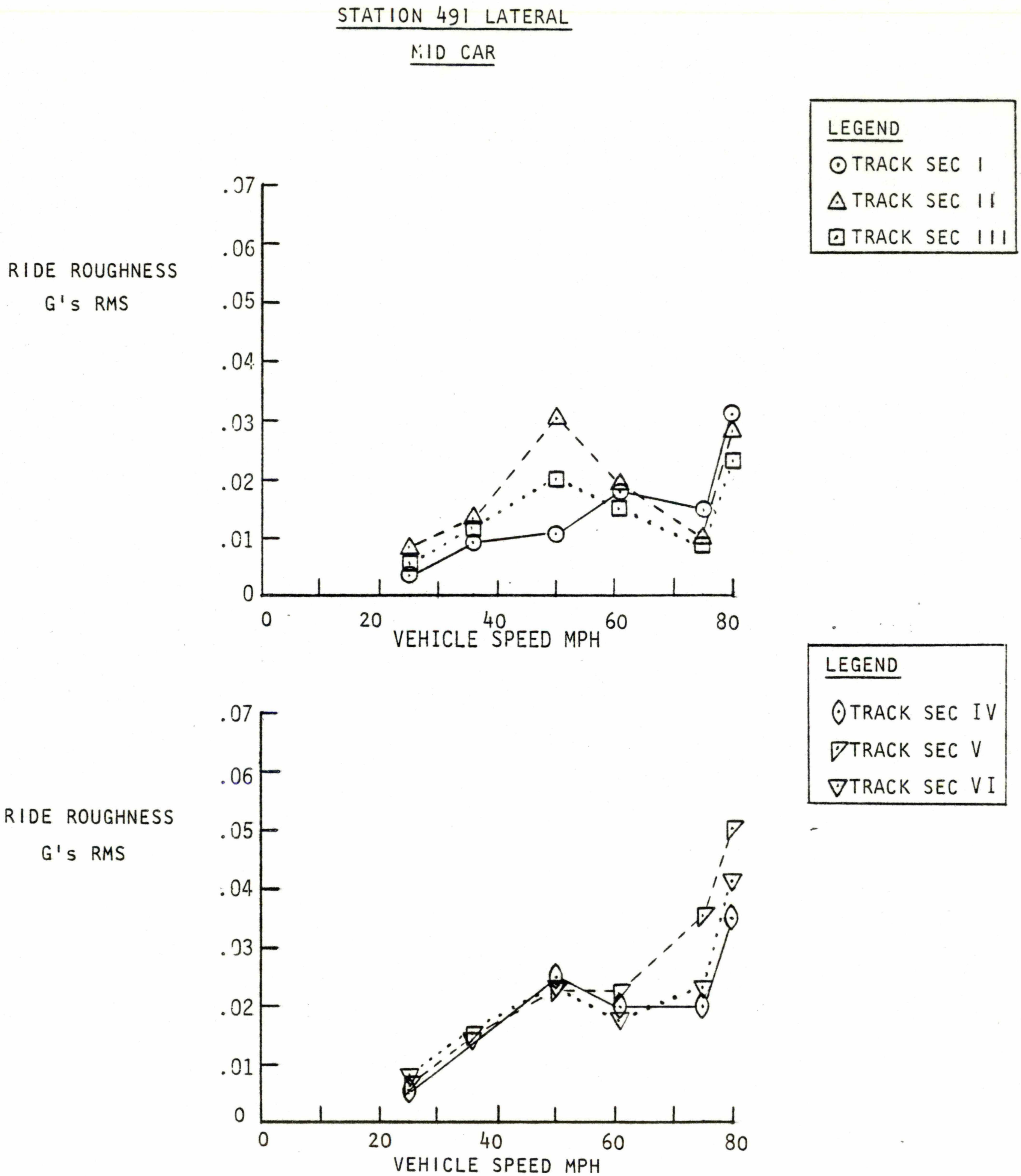


Figure 5–36. Effect of Vehicle Speed on Lateral Ride Roughness

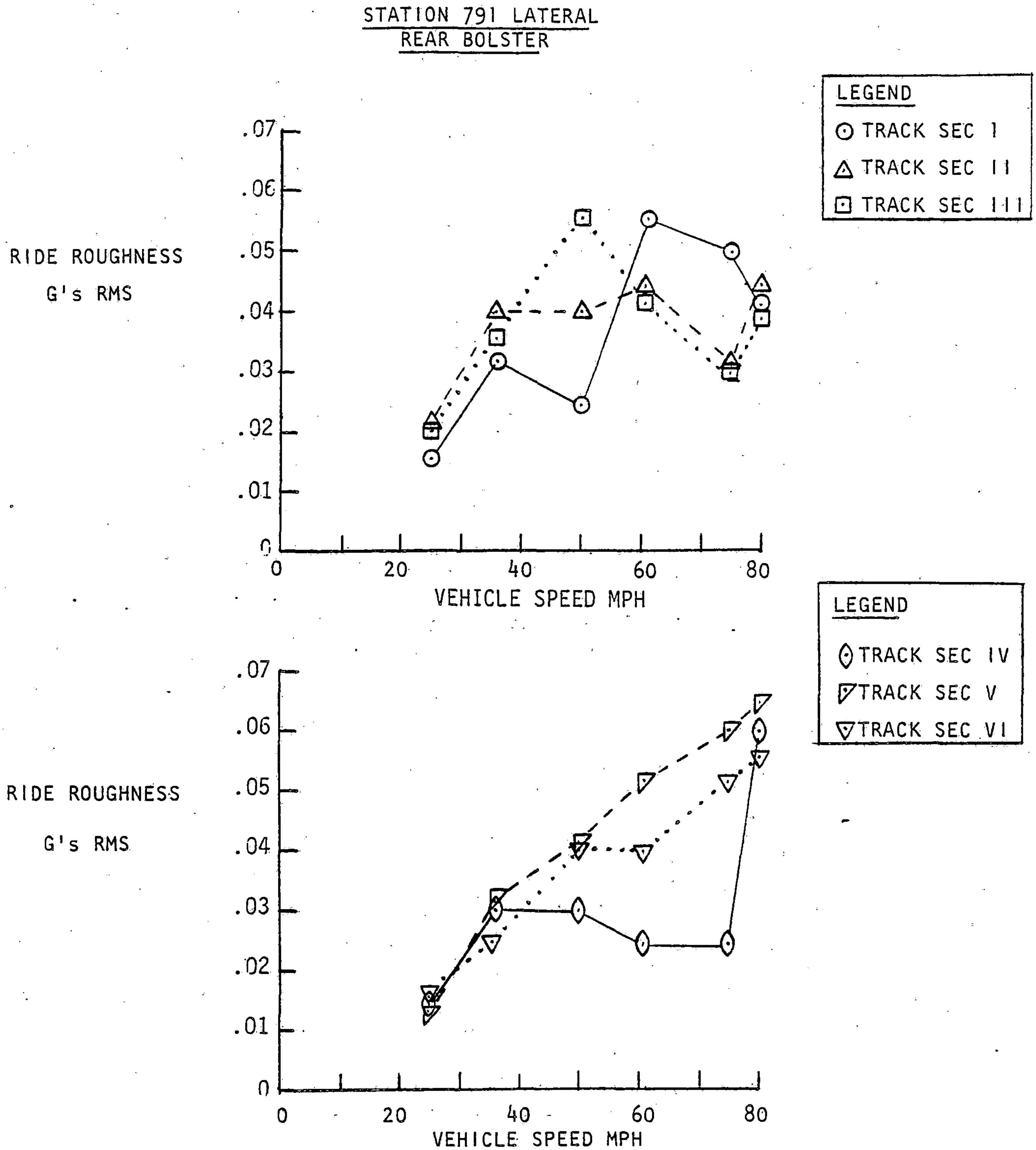


Figure 5–37. Effect of Vehicle Speed on Lateral Ride Roughness

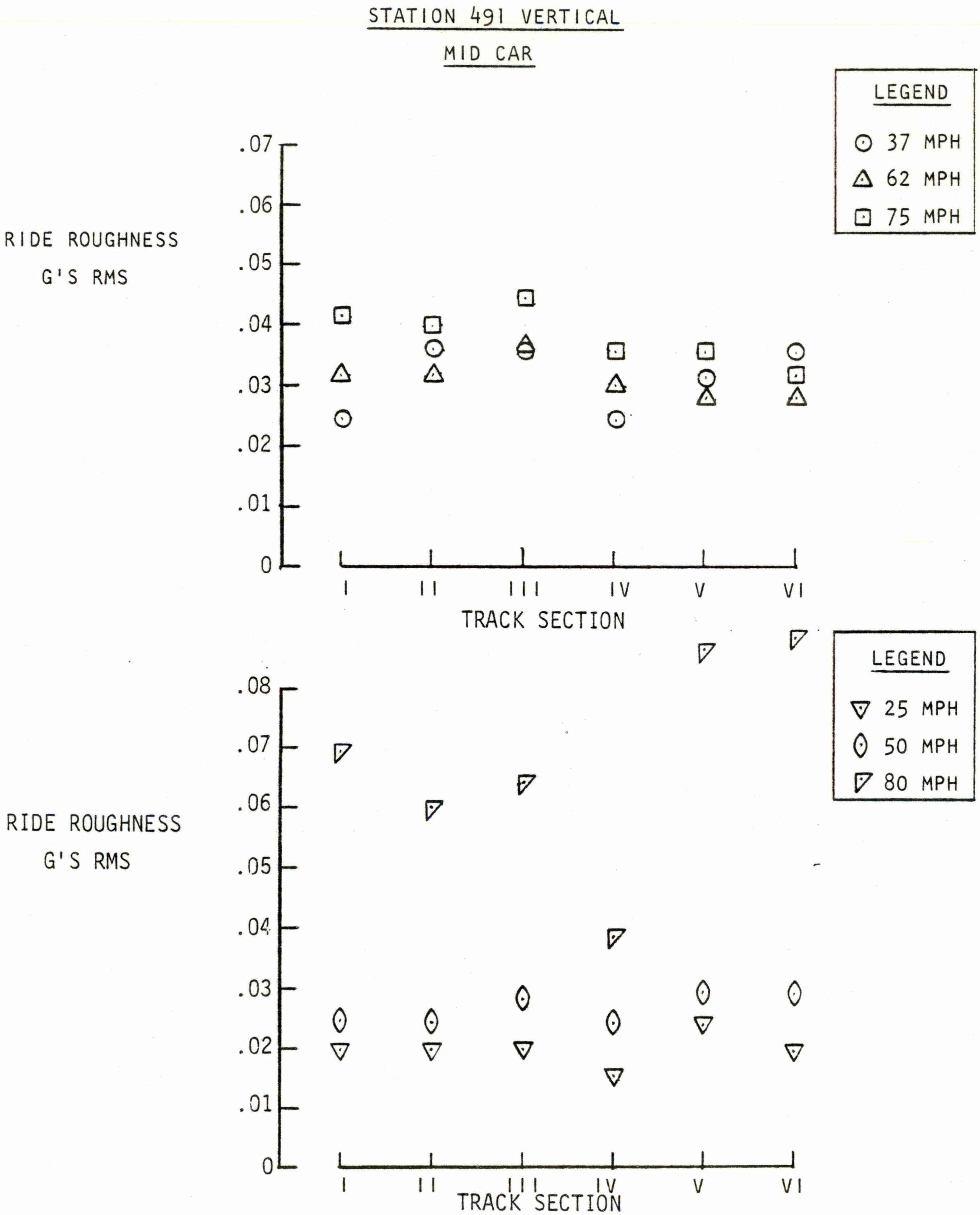


Figure 5–38. Effect of Track Section on Vertical Ride Roughness

STATION 648 VERTICAL

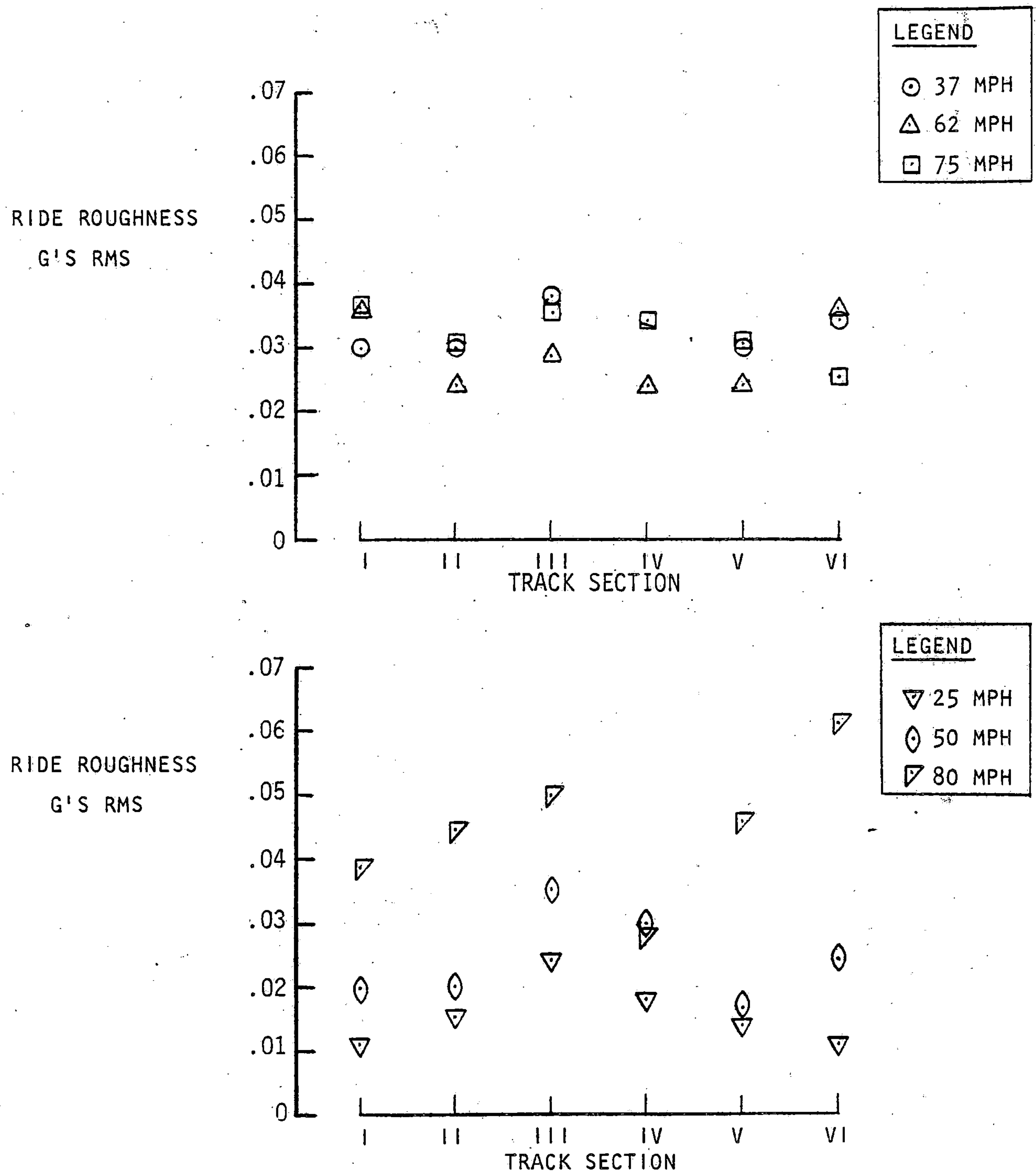


Figure 5–39. Effect of Track Section on Vertical Ride Roughness

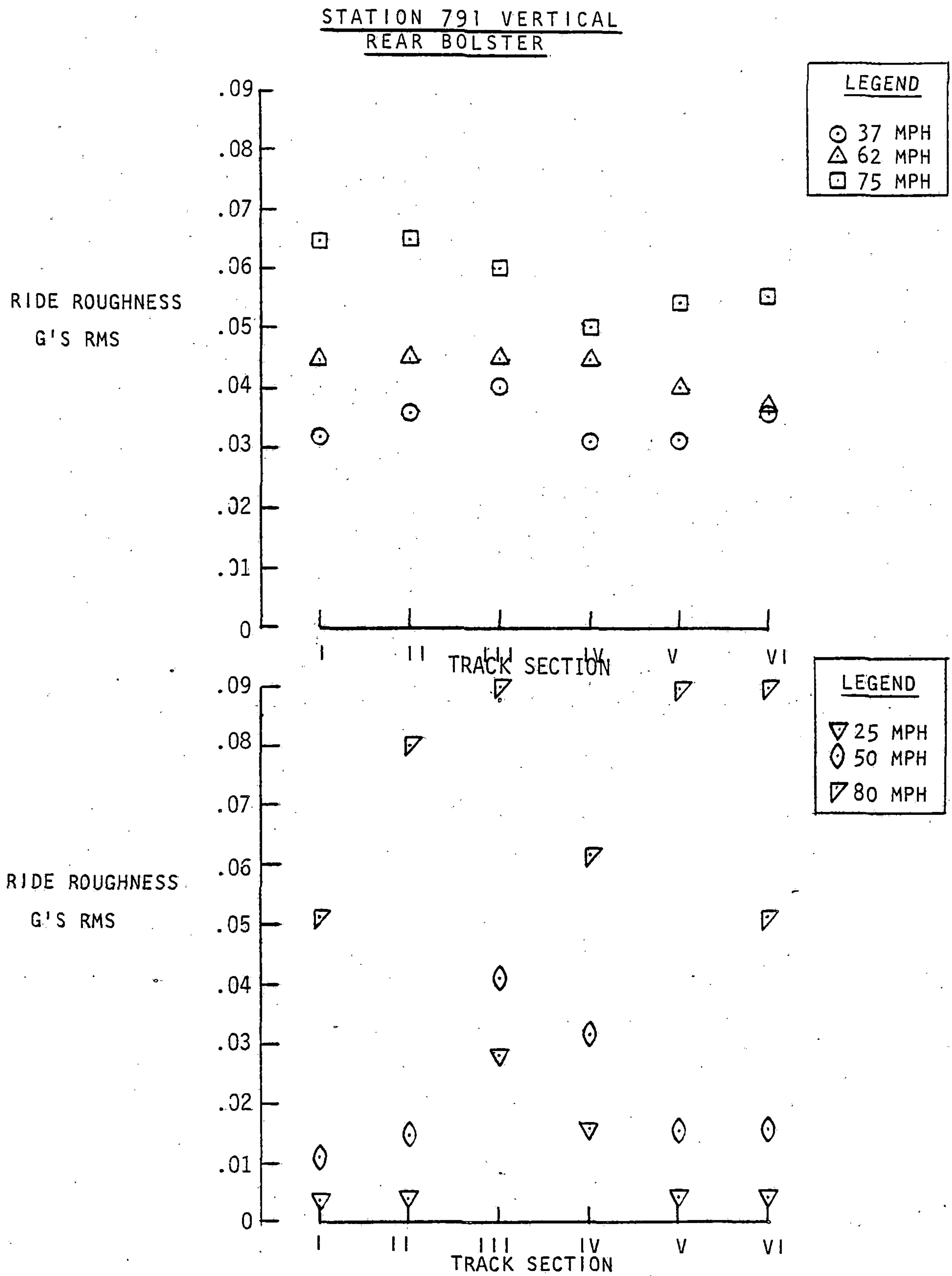


Figure 5–40. Effect of Track Section on Vertical Ride Roughness

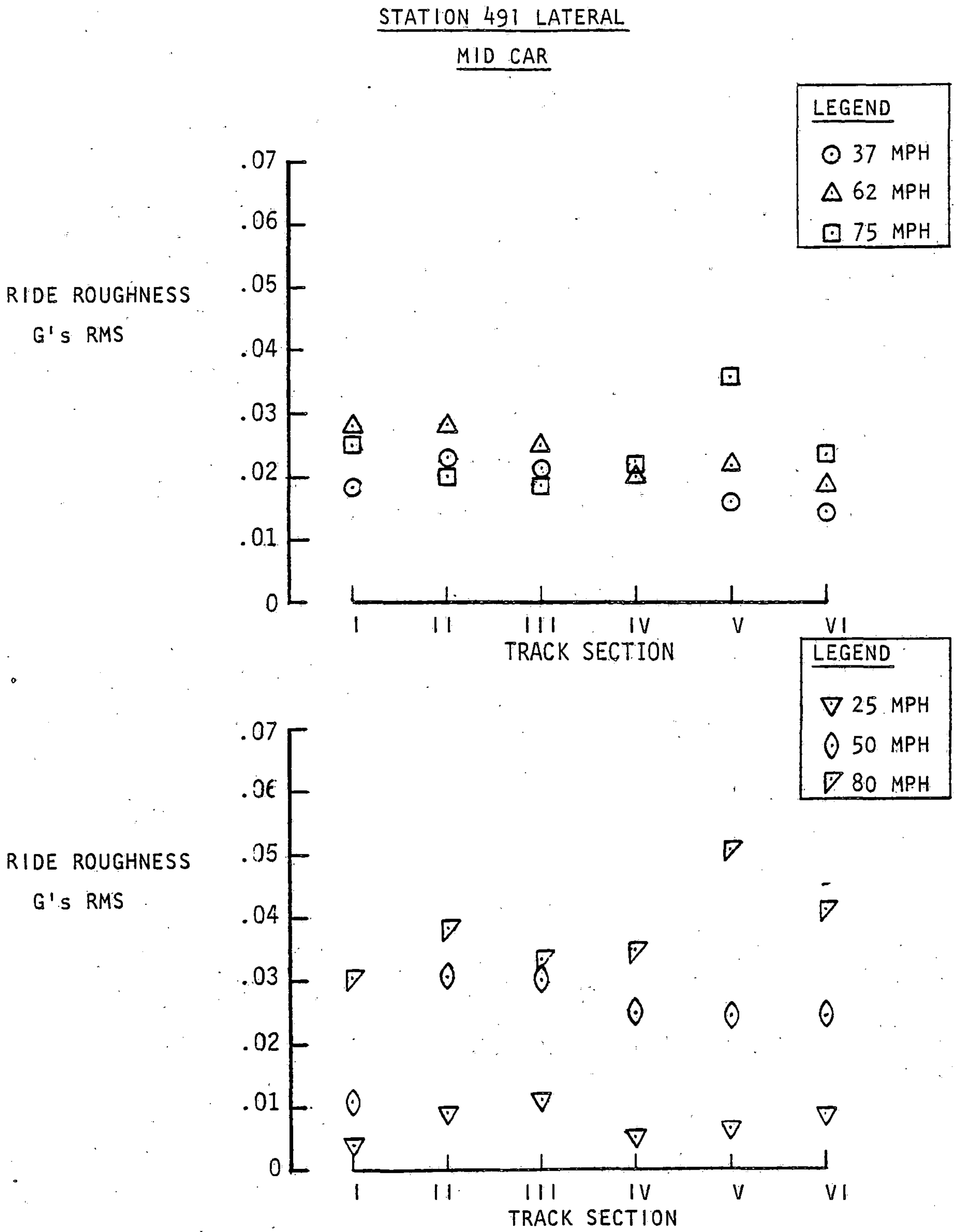
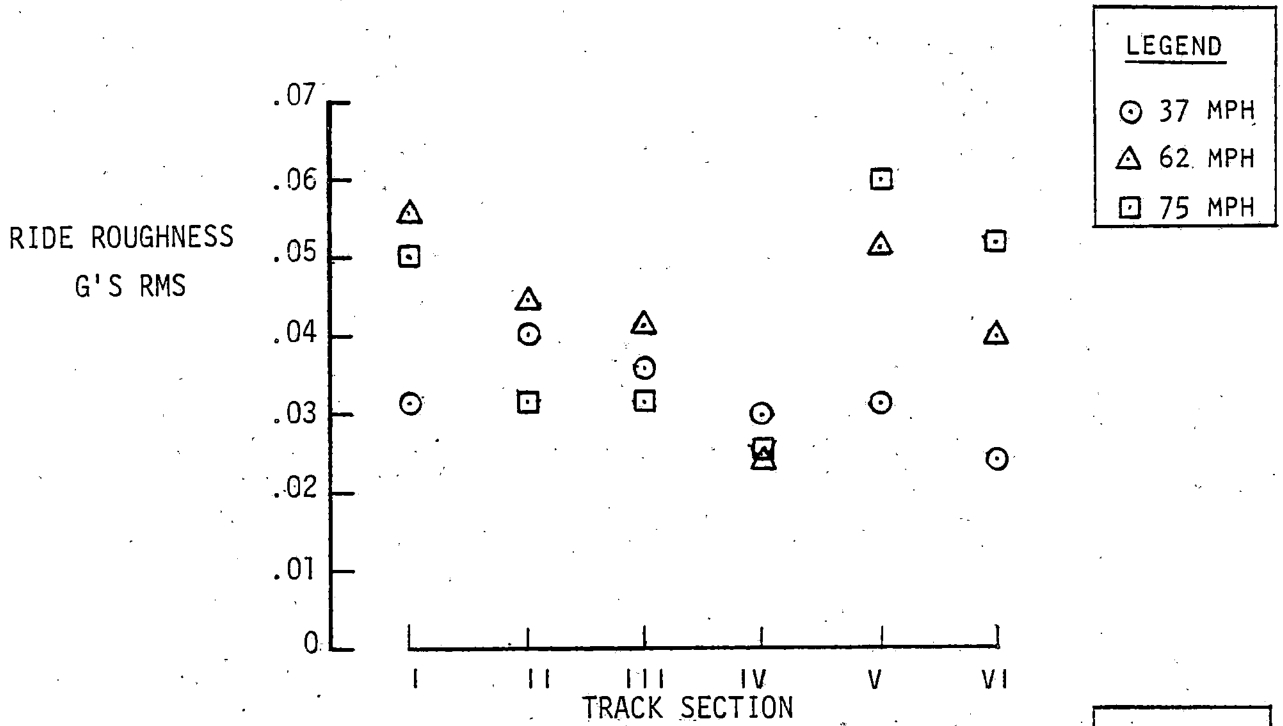


Figure 5–41. Effect of Track Section on Lateral Ride Roughness

STATION 791 LATERAL
REAR BOLSTER



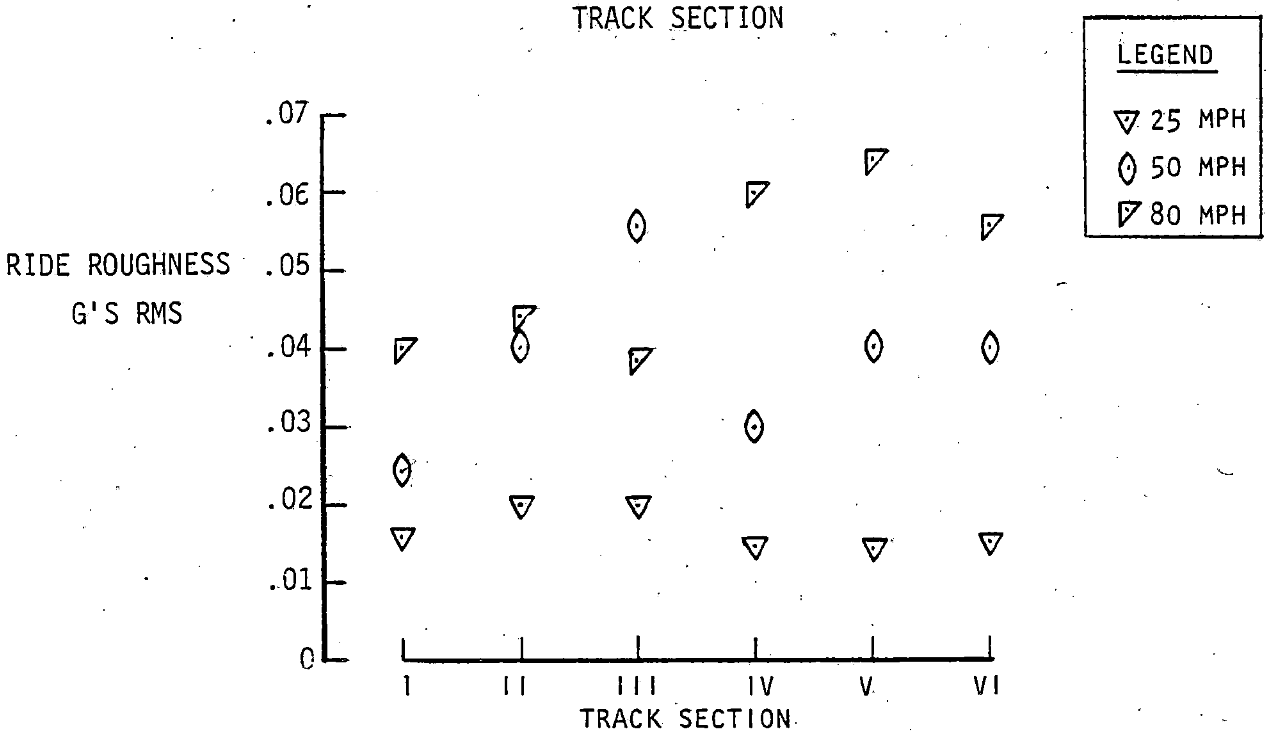


Figure 5–42. Effect of Track Section on Lateral Ride Roughness

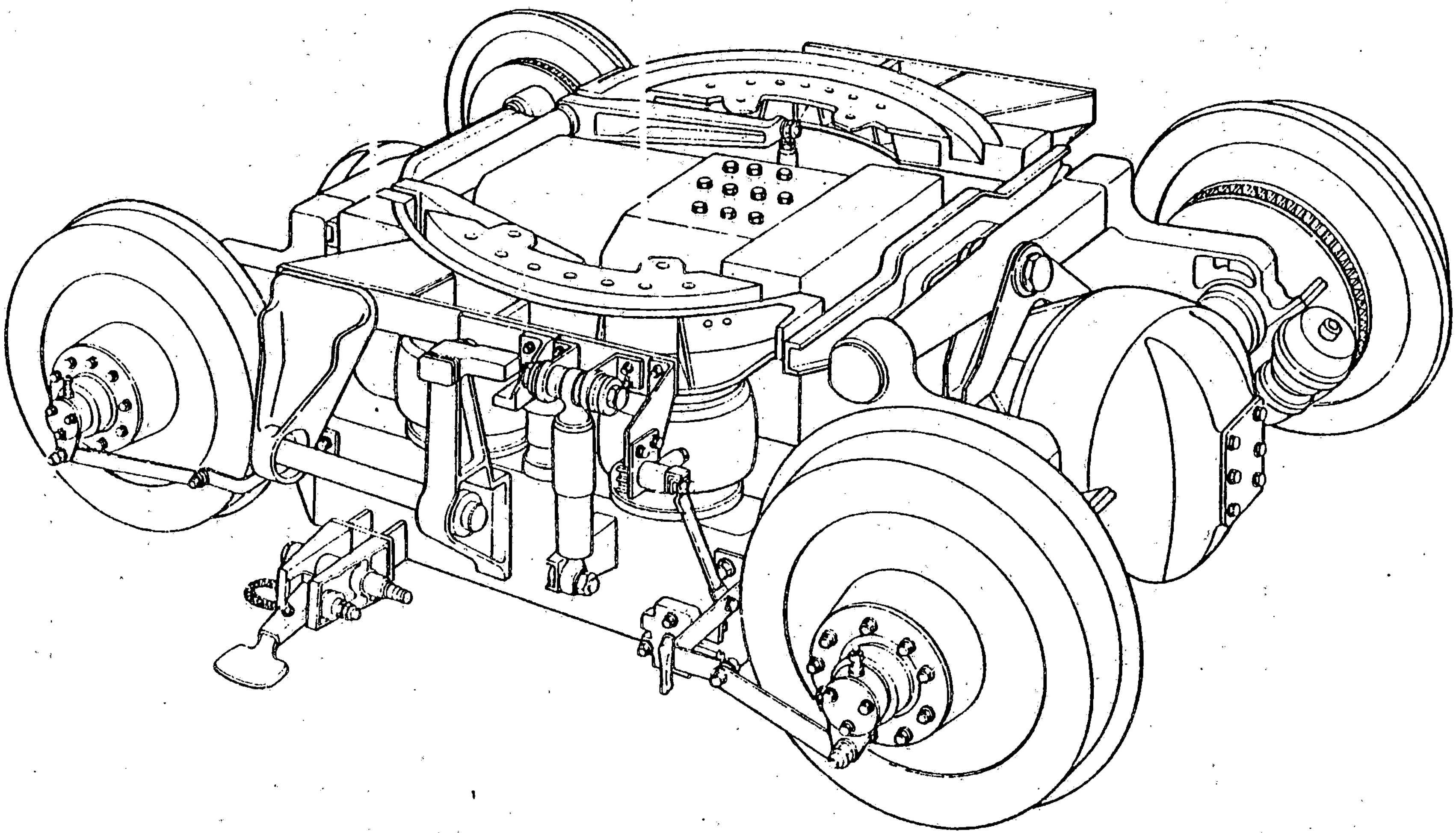


Figure 5–43. ACT-1 Truck

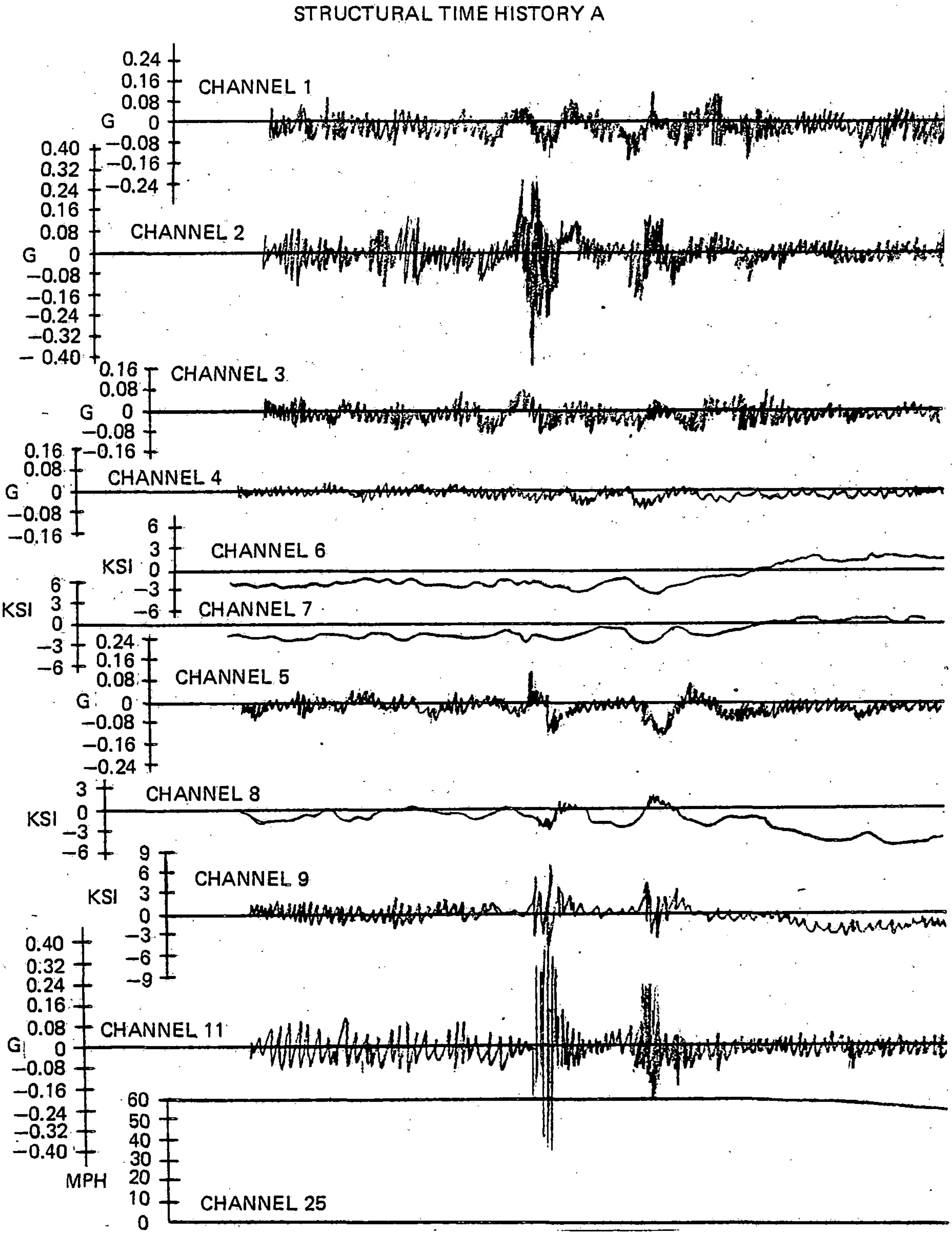


Figure 5–44. Sample Data Record (Sheet 1 of 2)

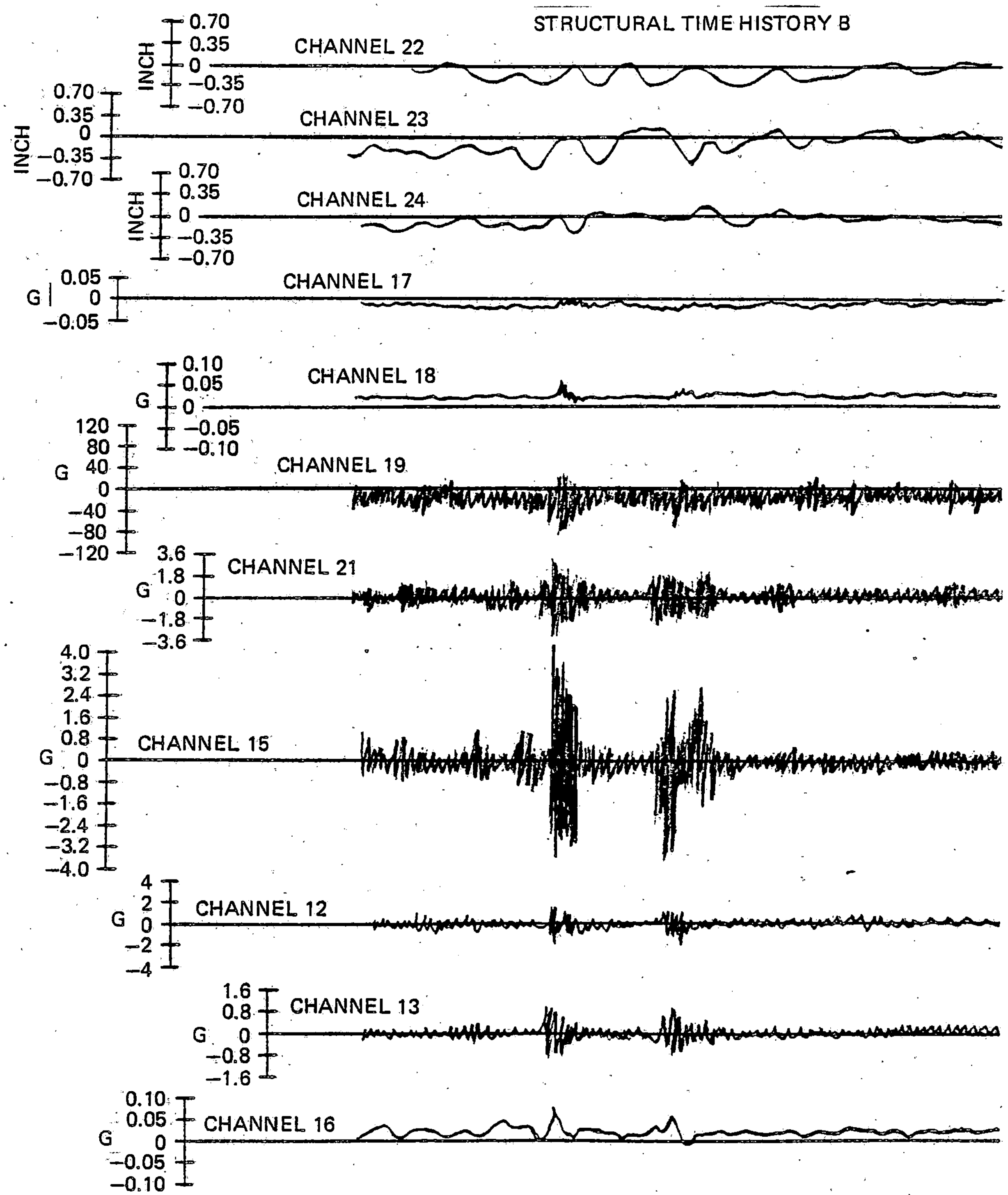


Figure 5–44. Sample Data Record (Sheet 2 of 2)

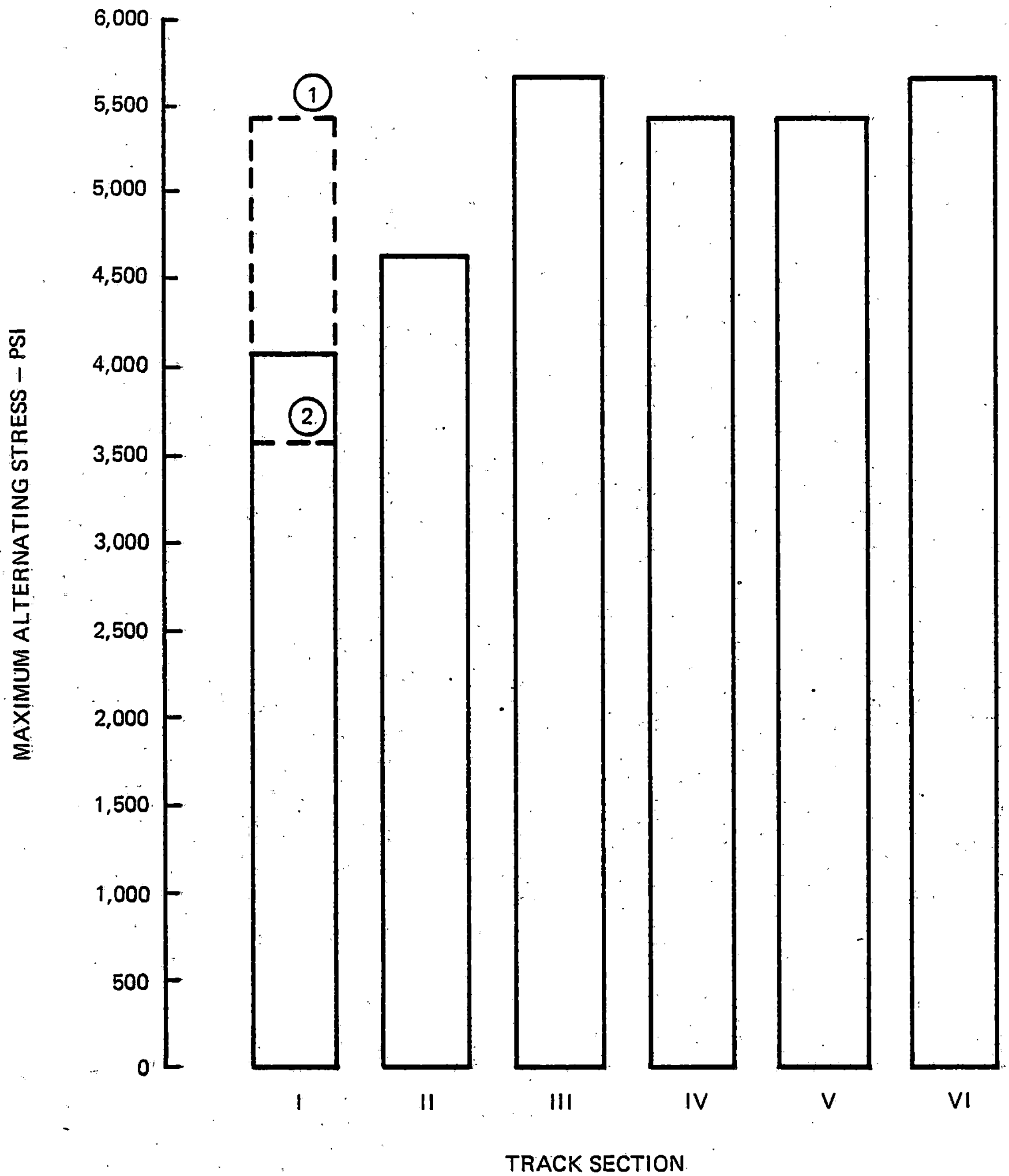


Figure 5–45. Truck Frame Stress Levels as a Function of Track Sections

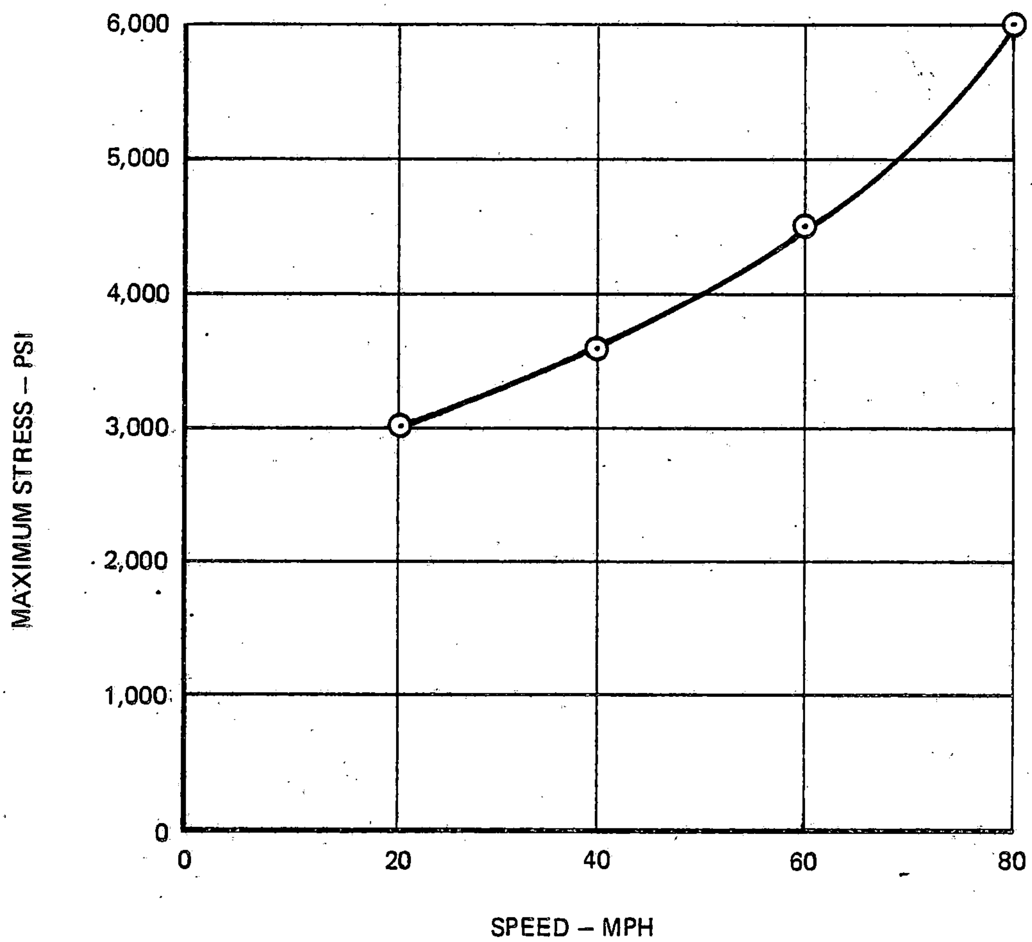


Figure 5–46. Truck Frame Strain Levels as a Function of Speed

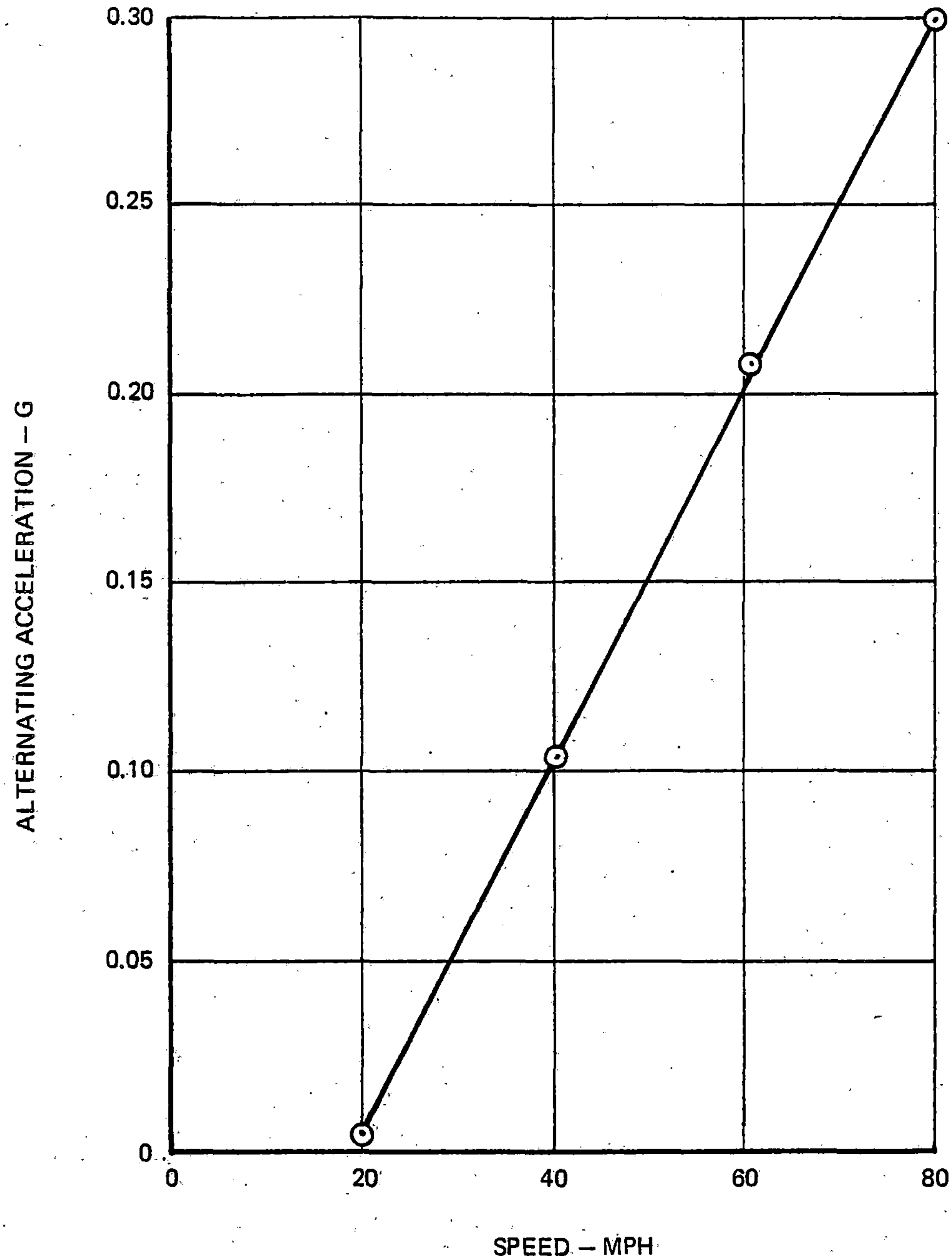


Figure 5–47. Traction Motor Vertical Acceleration as a Function of Speed

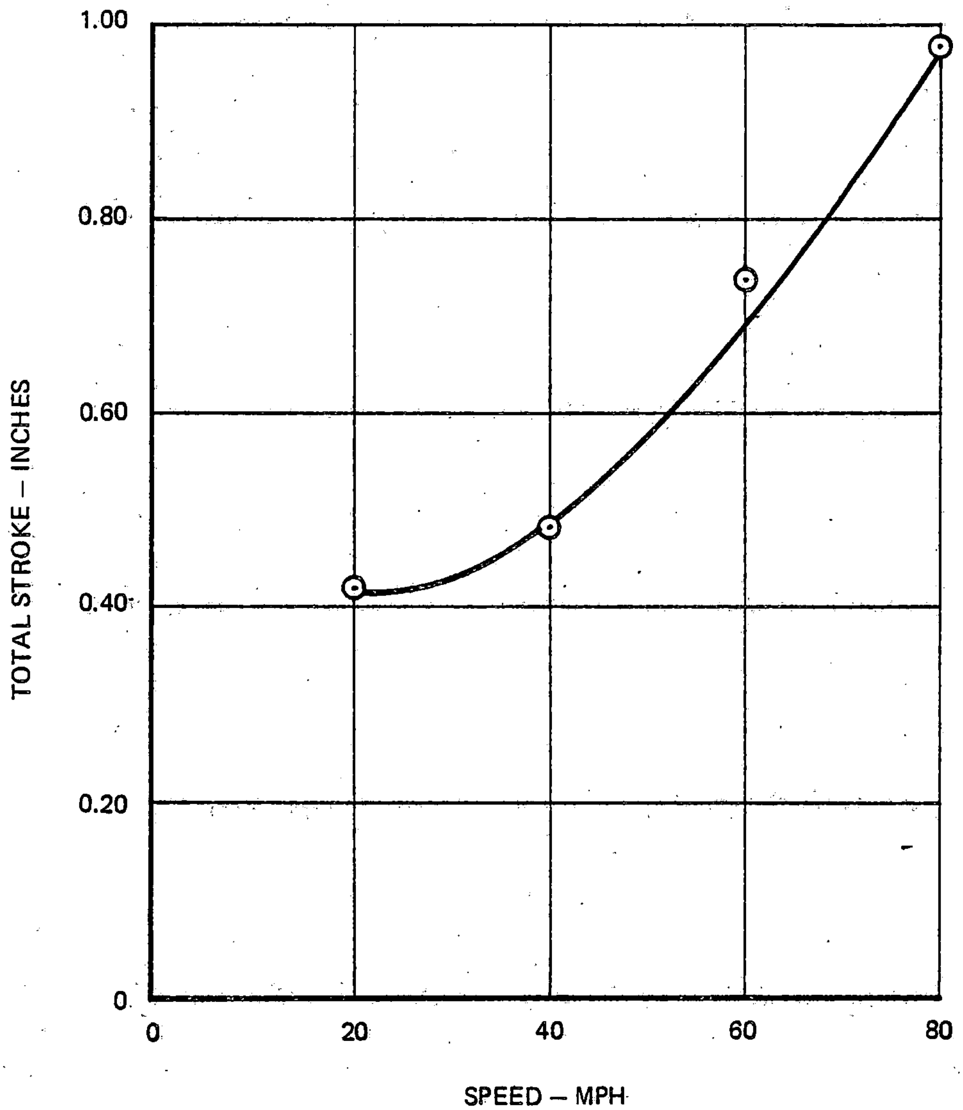


Figure 5–48. B Truck Right Airspring Vertical Displacement as a Function of Speed

- 31 IN. DIAMETER NEW WHEELS
- 39 FT. TRACK, STAGGERED SPACING

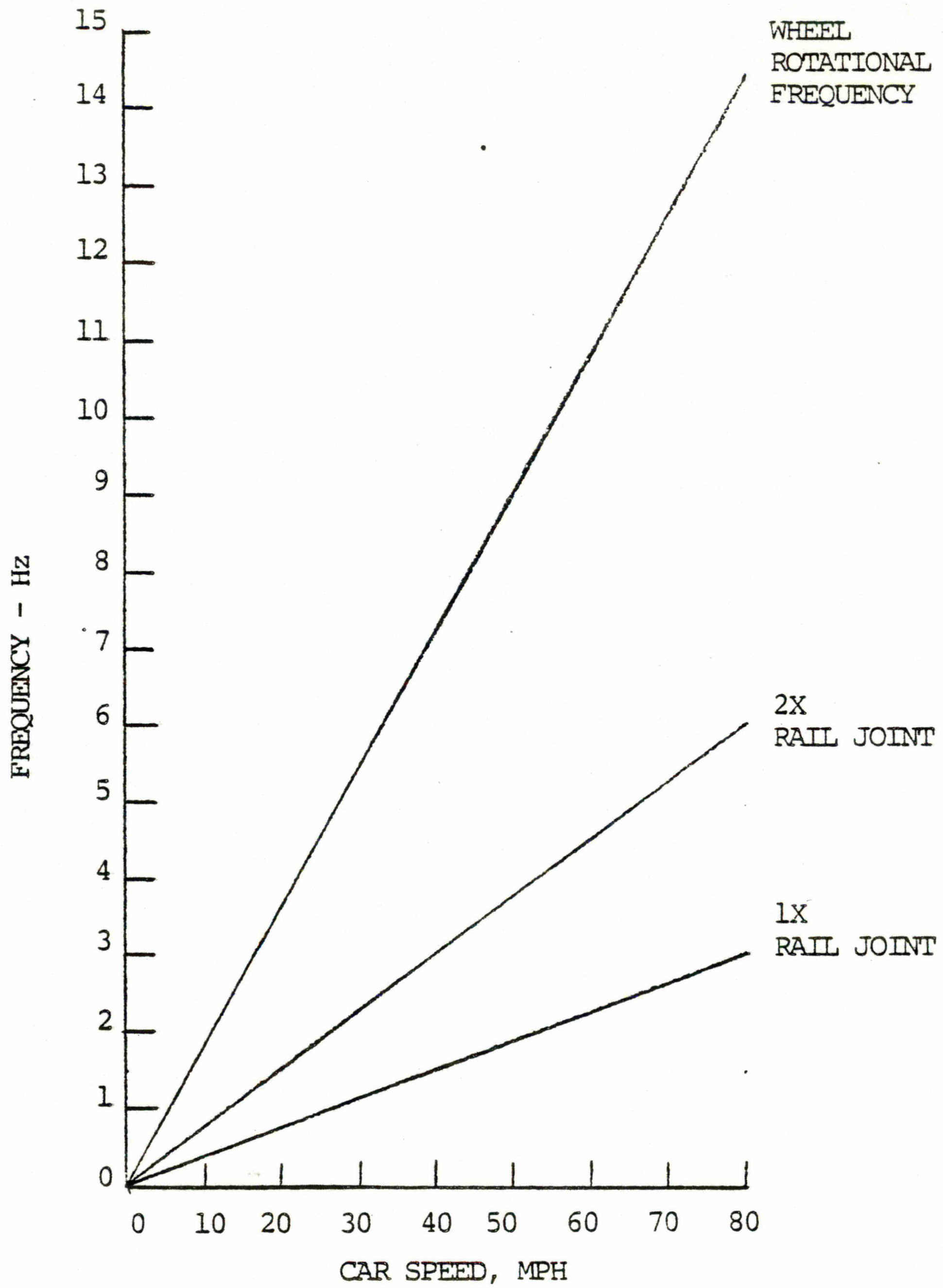


Figure 5–49. Excitation Frequency Spectrum

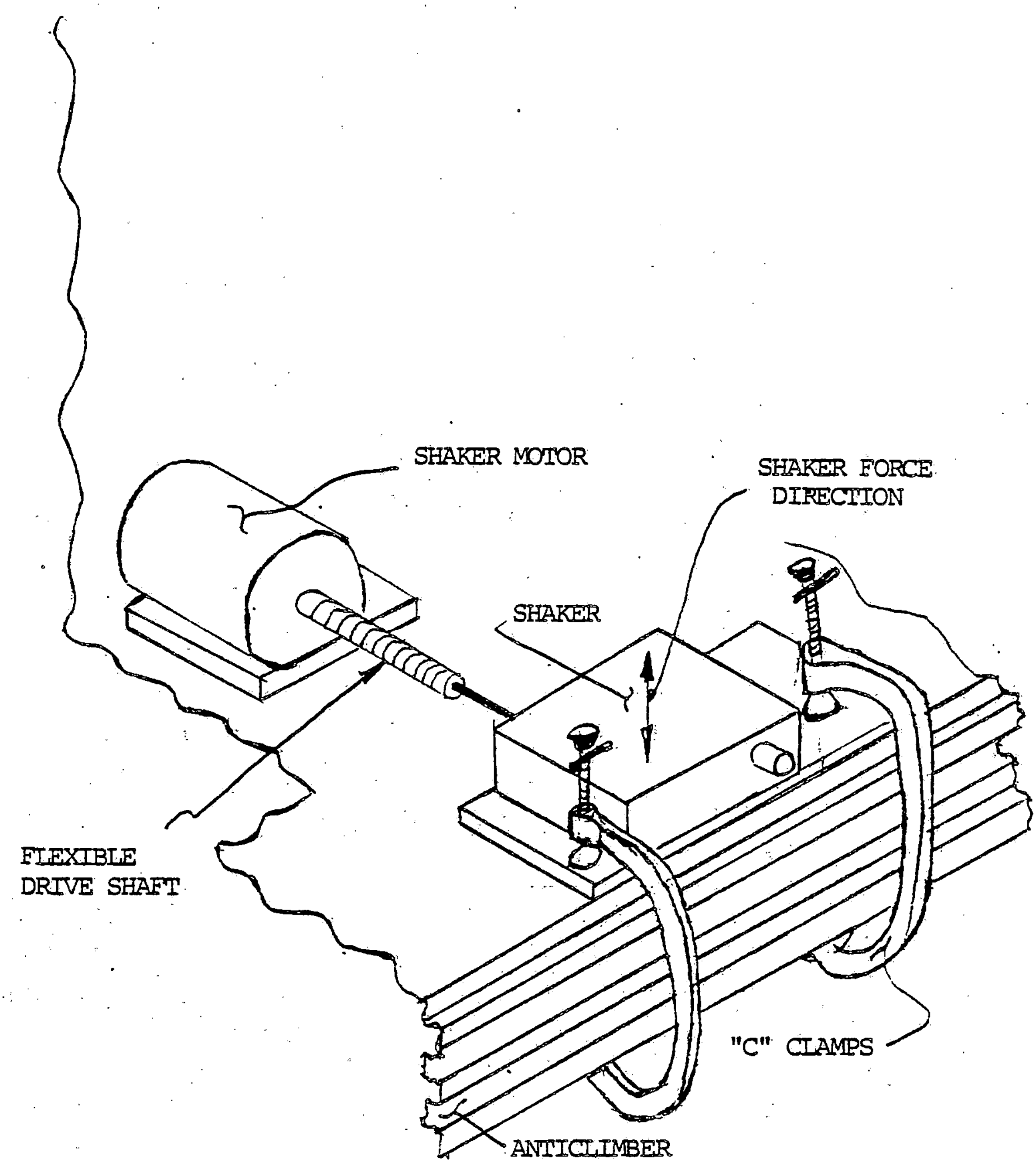


Figure 5–50. Shake Test Vertical Shaker Installation

- SHAKER LOCATION-ANTICLIMBER CENTERLINE
- CAR WEIGHT-AW3
- SHAKER FORCE-500 LBS
- EXCITATION-VERTICAL

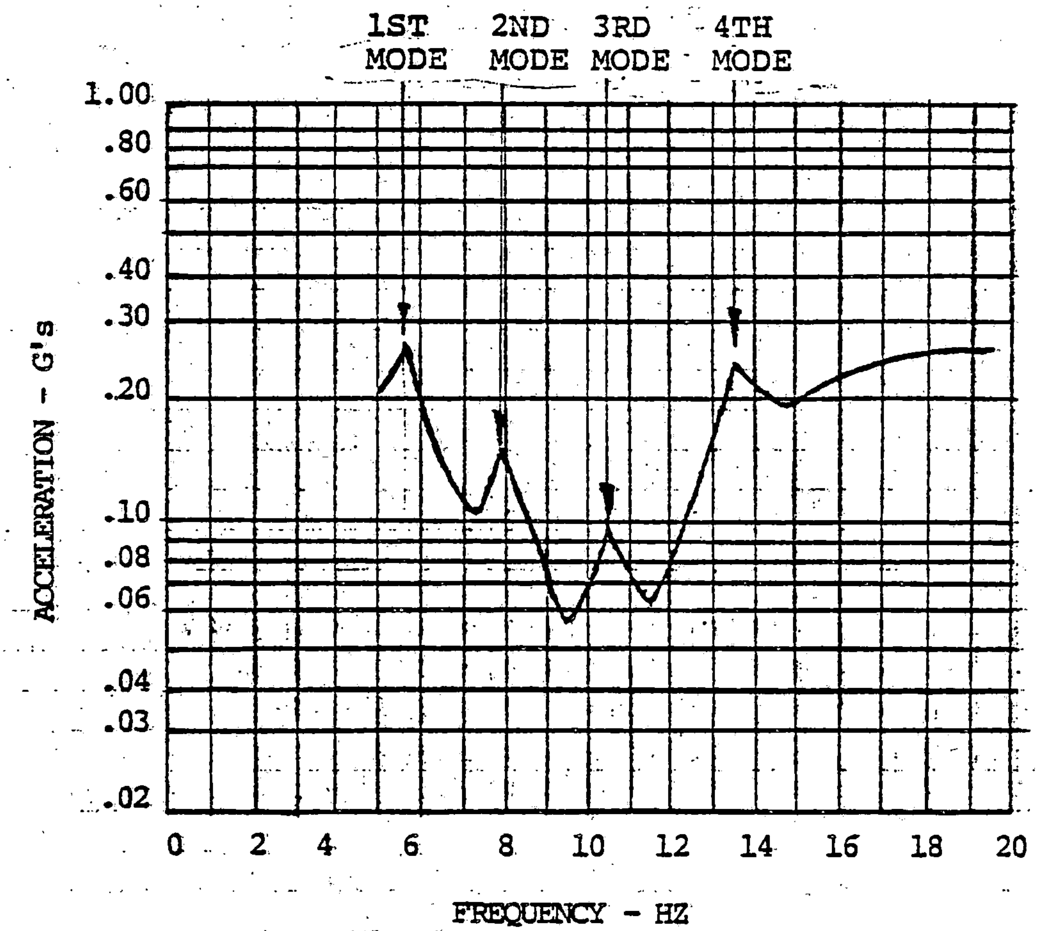
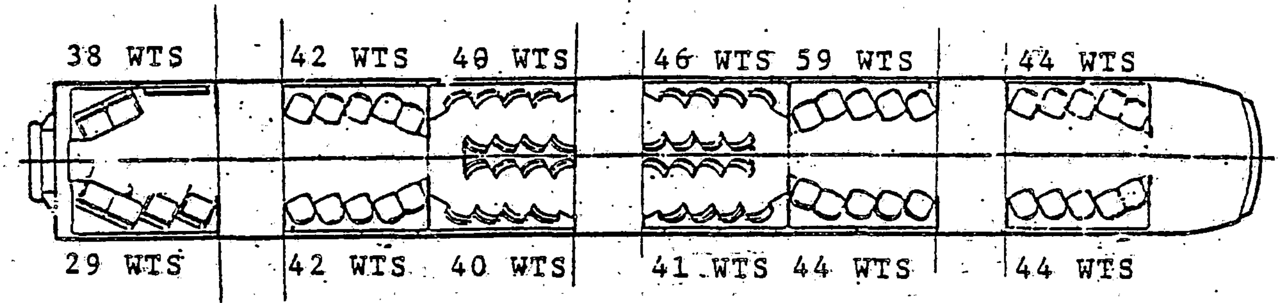


Figure 5–51. Shake Test Typical Acceleration Response Curve

- AW2 CONFIGURATION
- TEST WEIGHT = 116,000 LBS
- TOTAL BALLAST = 25,000 LBS (509 WTS)



- AW3 CONFIGURATION
- TEST WEIGHT = 131,750 LBS
- TOTAL BALLAST - 40,750 LBS (837 WTS)

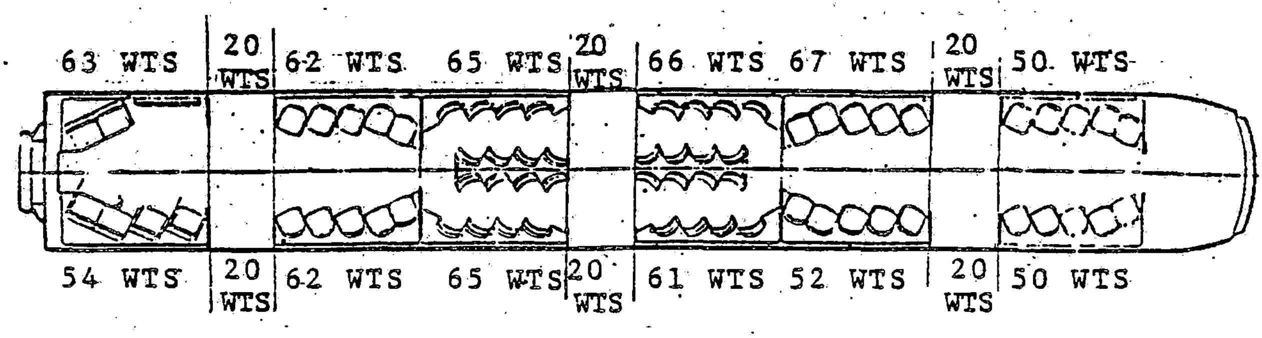


Figure 5–52. Shake Test Ballast Distribution

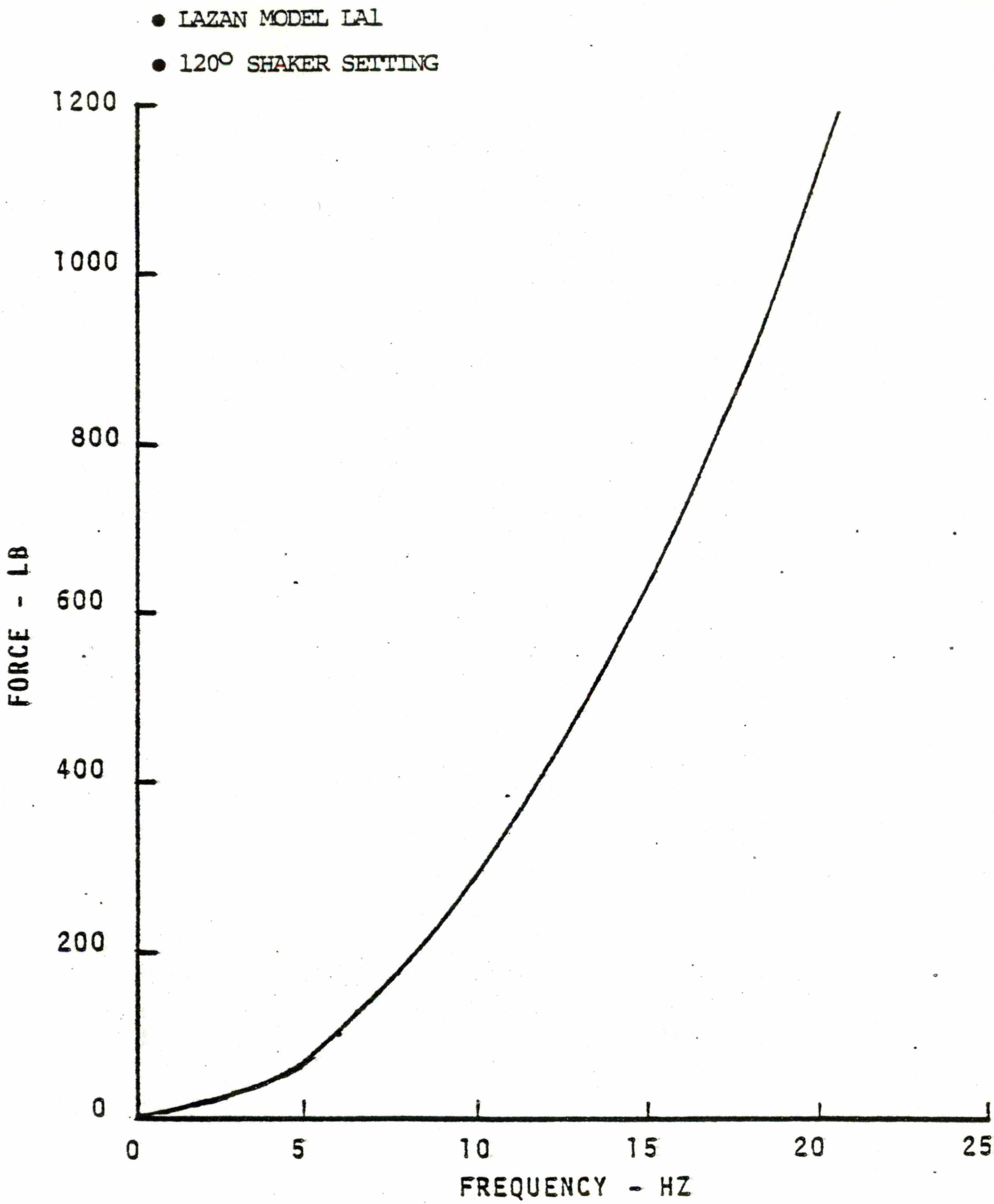


Figure 5–53. Shaker Force/Frequency Characteristics

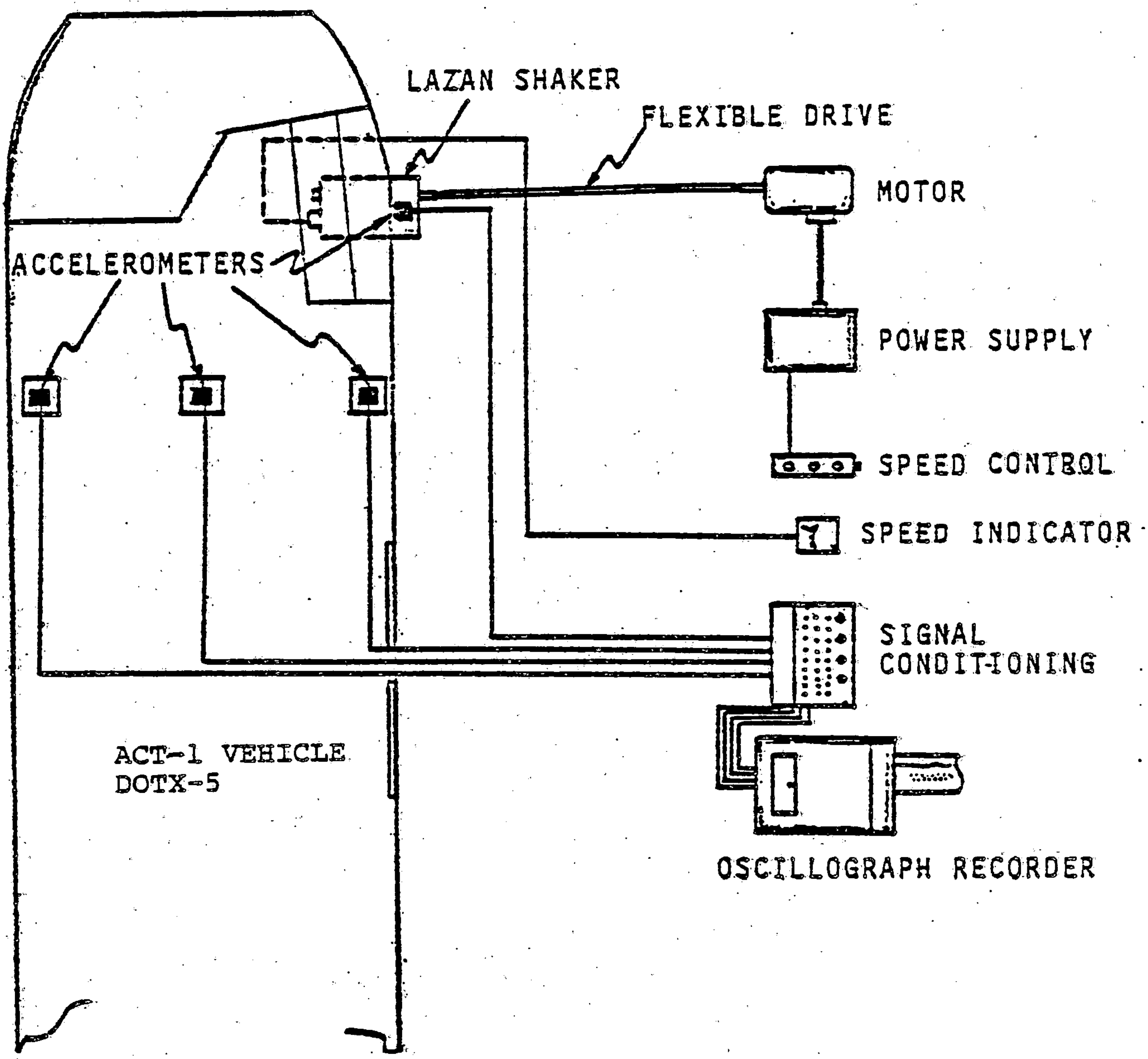


Figure 5–54. Test Equipment Block Diagram

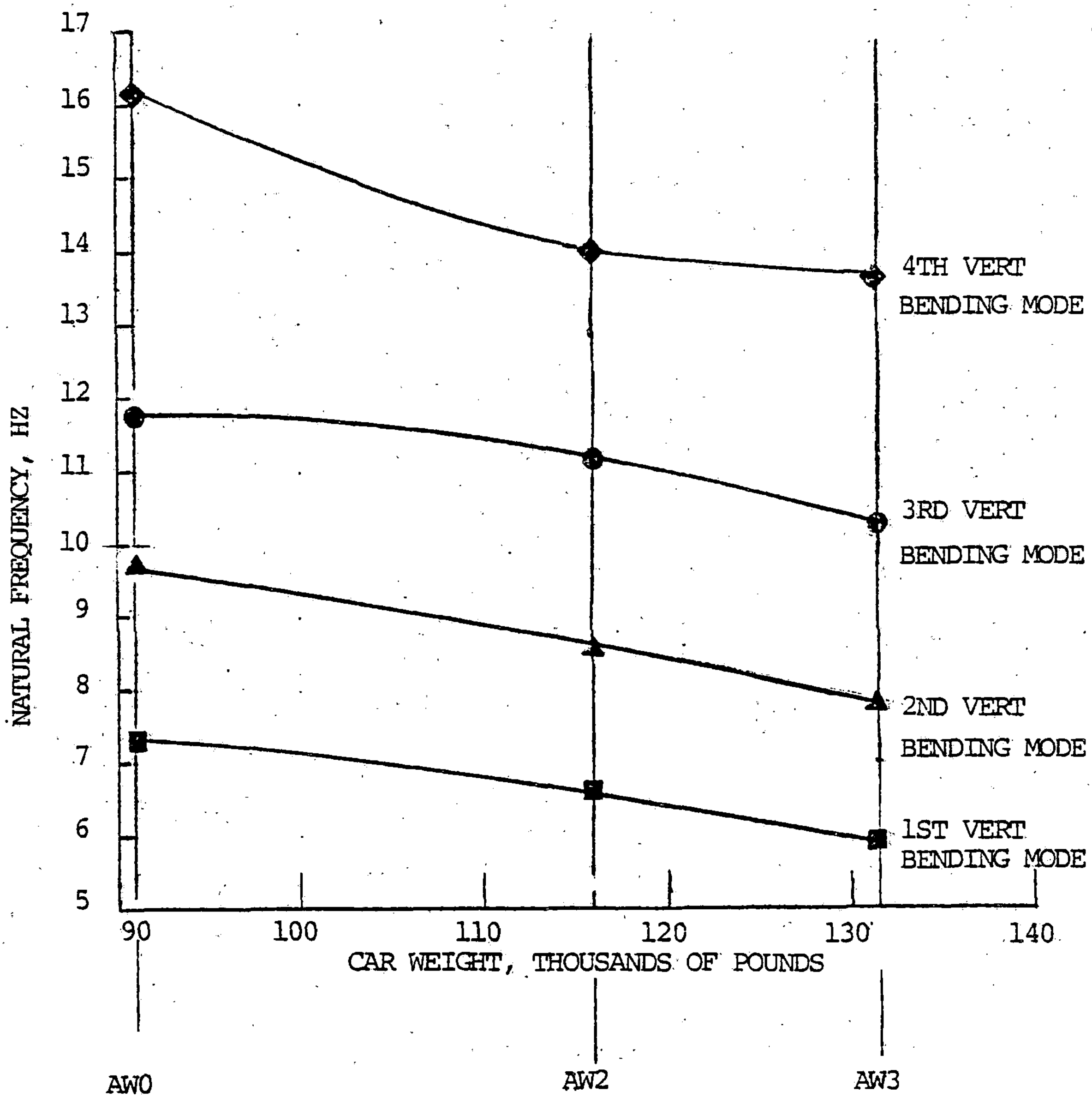


Figure 5–55. Shake Test, Vertical Shake Test Summary

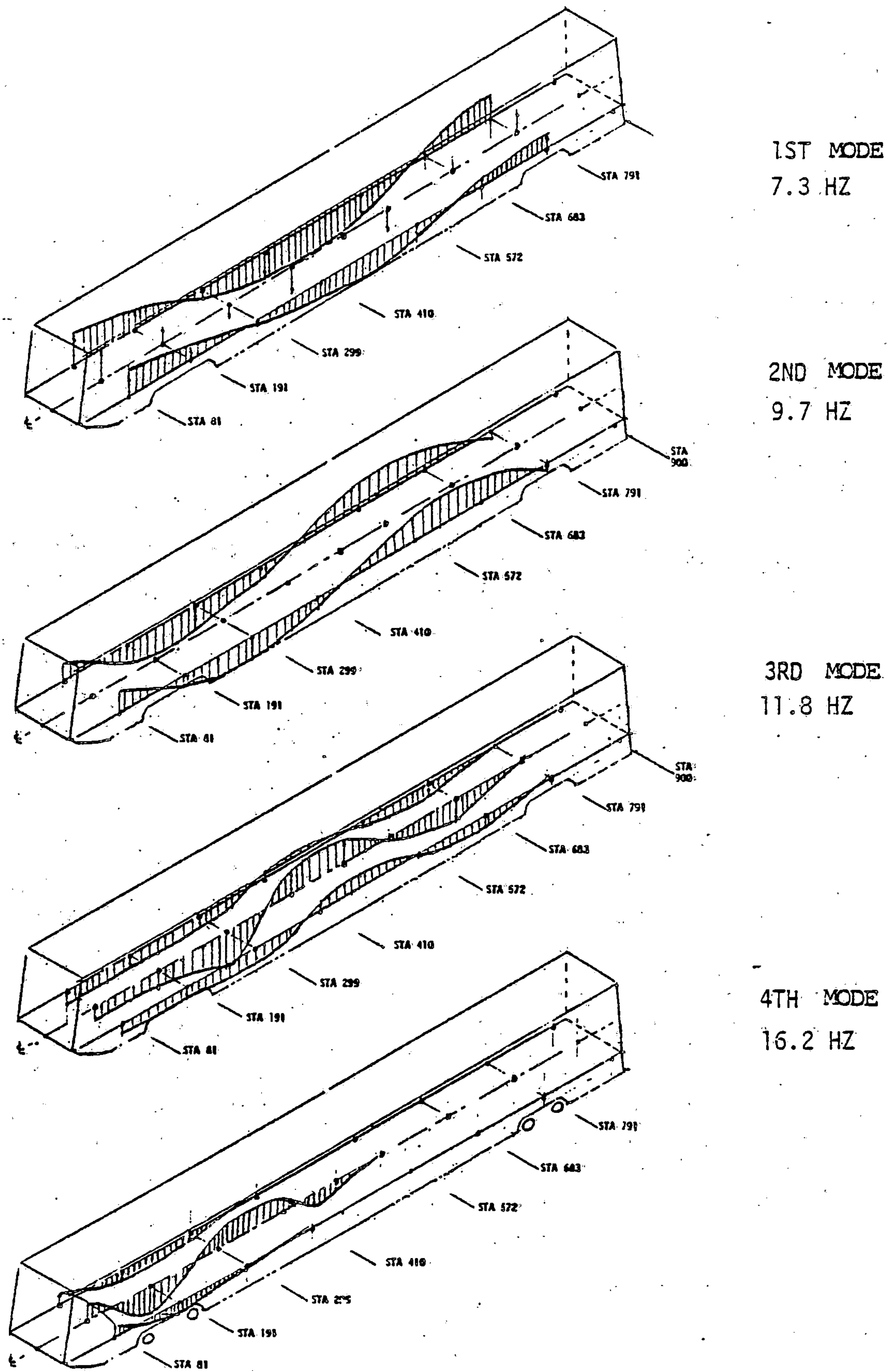


Figure 5–56. Shake Test, Vertical Mode Shapes at AWO Car Weight

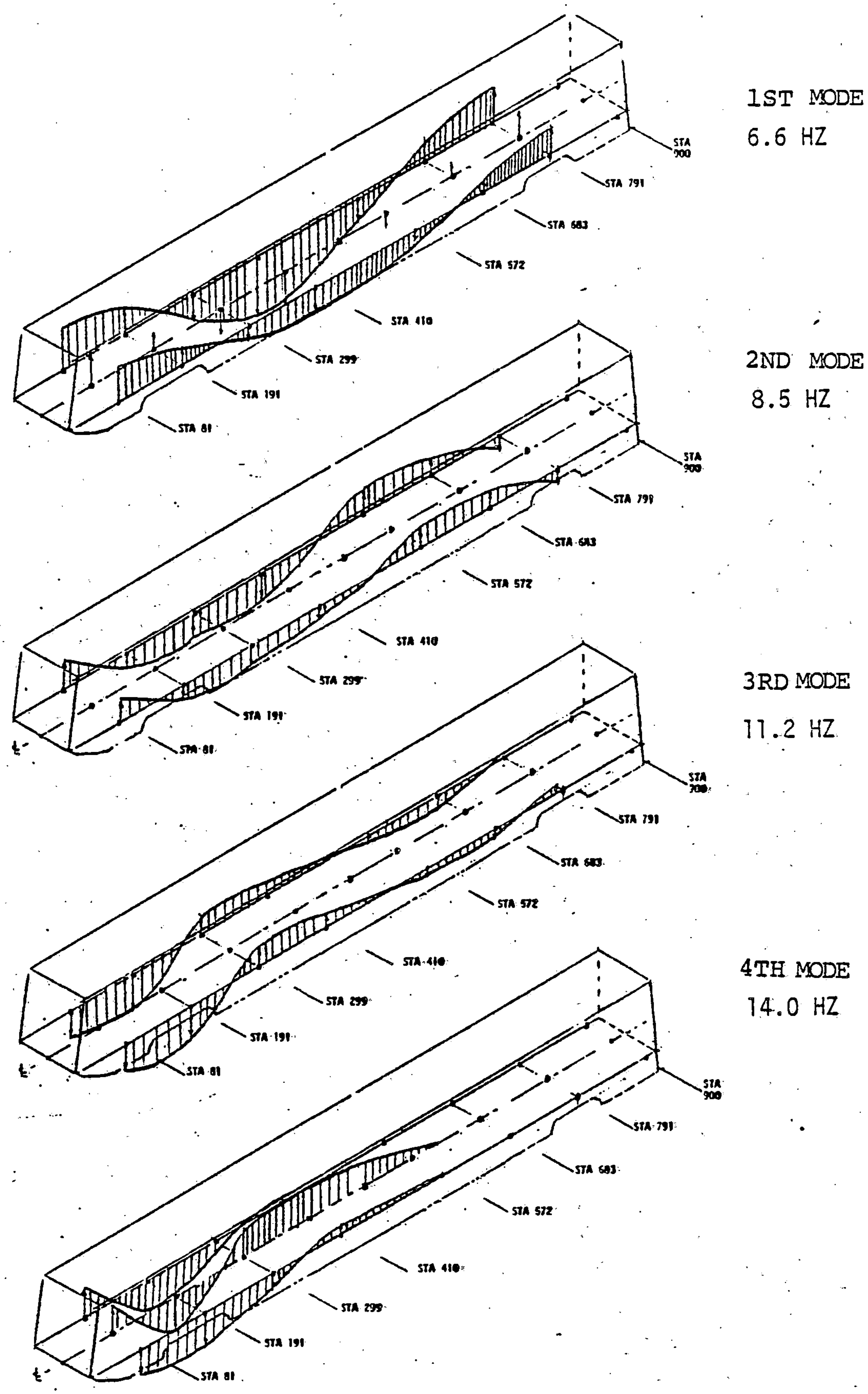


Figure 5–57. Shake Test, Vertical Mode Shapes at AW2 Car Weight

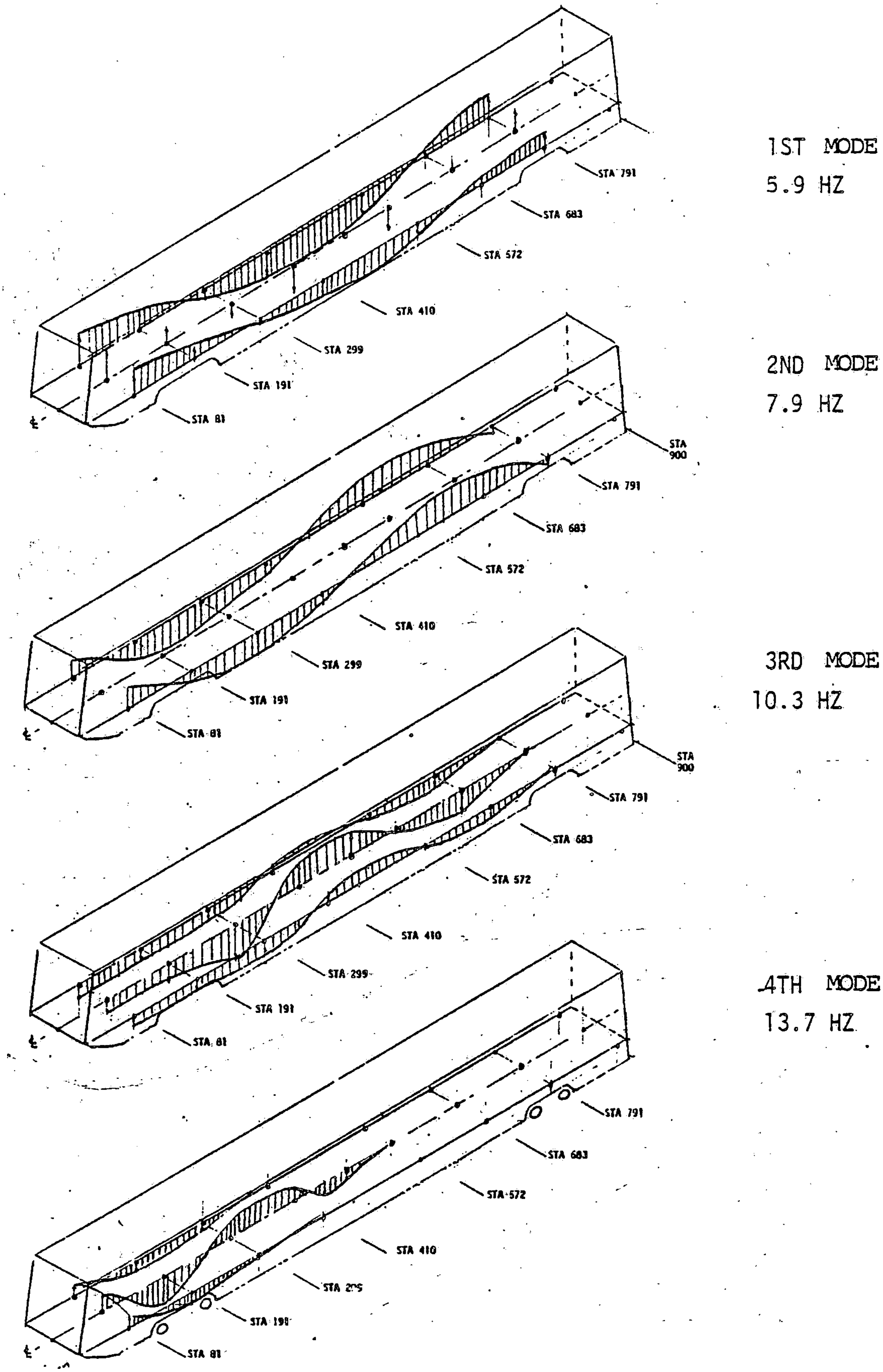


Figure 5–58. Shake Test, Vertical Mode Shapes at AW3 Car Weight

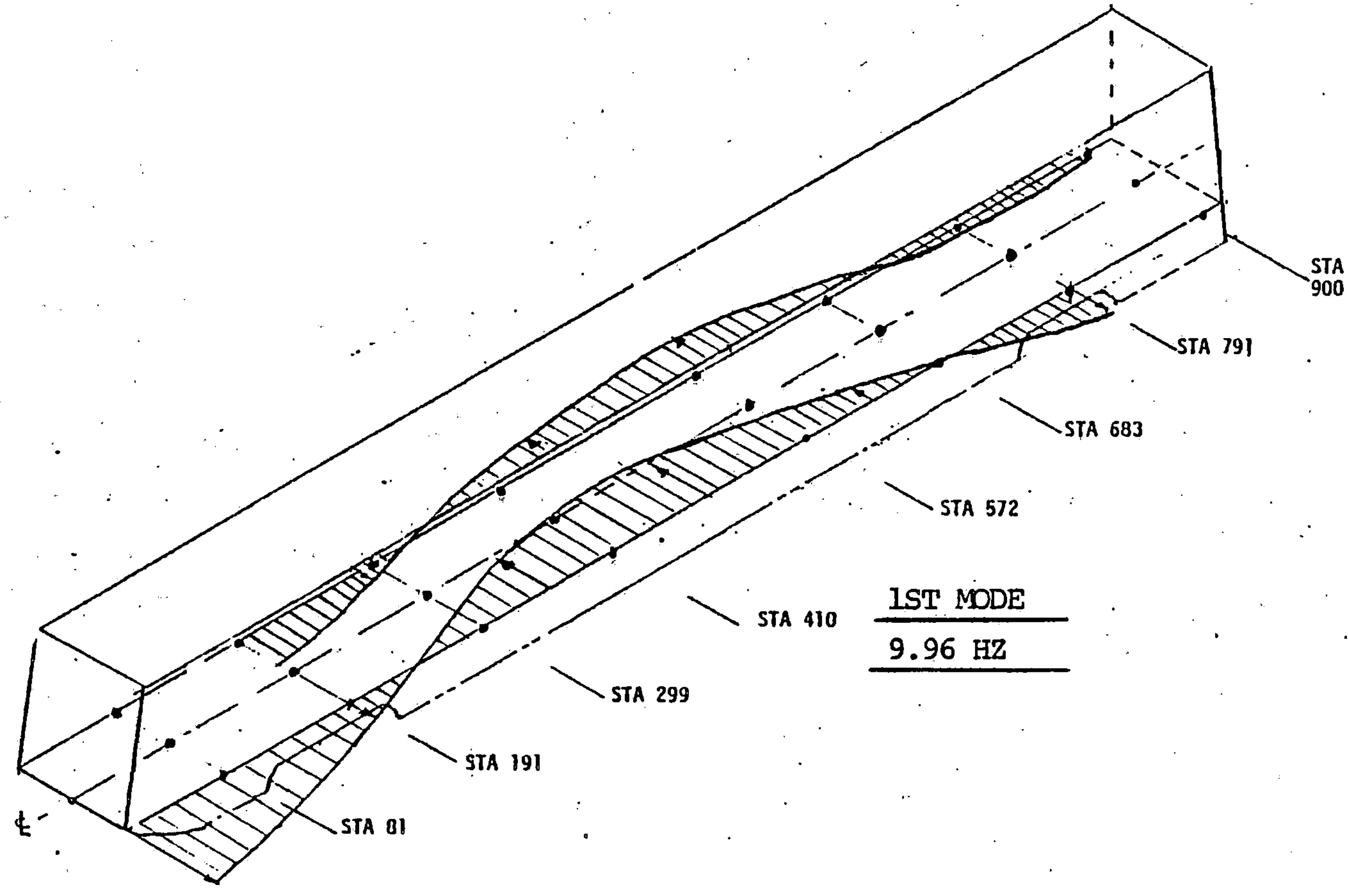


Figure 5–59. Shake Test, Lateral/Torsional Mode Shape at AWO Car Weight

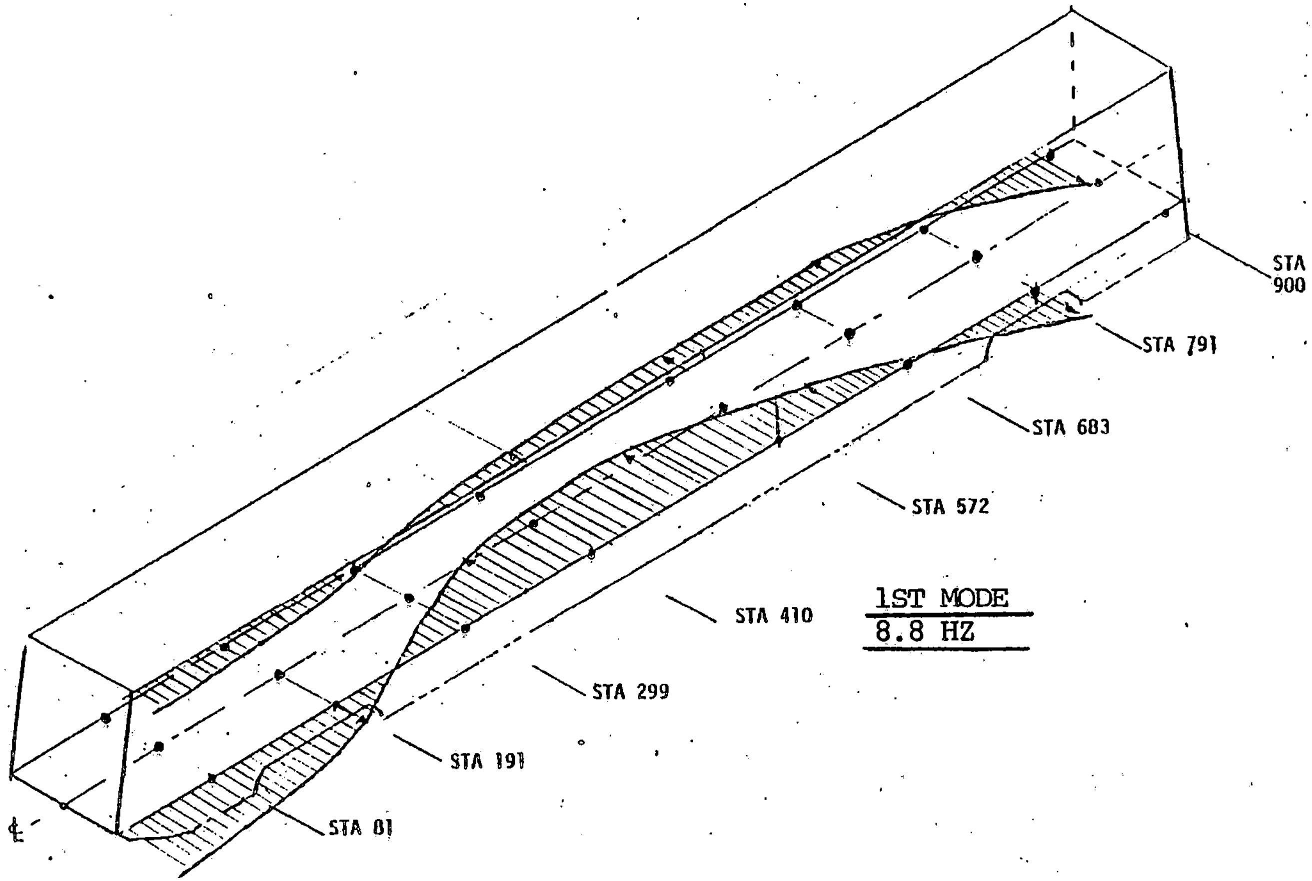


Figure 5–60. Shake Test, Lateral/Torsional Mode Shapes at AW2 Car Weight

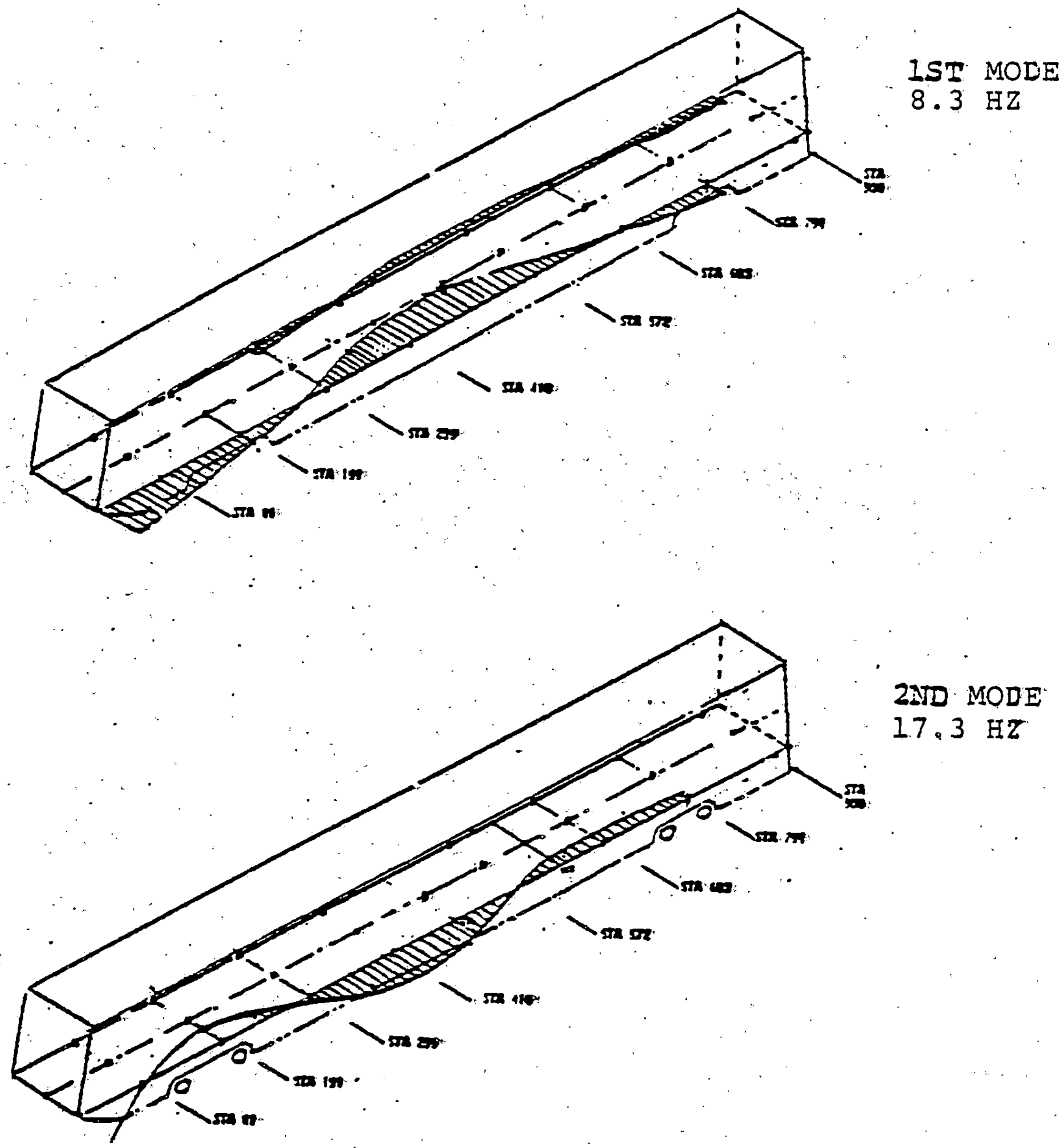


Figure 5–61. Shake Test, Lateral/Torsional Mode Shapes at AW3 Car Weight

6.0 ACOUSTICS

6.1 SUMMARY

The ACT-1 car interior and wayside acoustic levels were determined for a static vehicle as well as accelerating, steady speed, and decelerating conditions.

The interior acoustic levels are highest at the carbody center compartment between the two energy storage units and lowest in the cab area. The predominant noise source is the energy storage units, with a noticeable beat between the two units. Interior noise levels decrease with discharging flywheels and increase with charging flywheels.

The wayside noise levels show a general increase with increasing car passby speed. However, it is significant to note that noise levels during acceleration and deceleration are lower than steady-state passby noise.

6.2 OBJECTIVE

The objective of the noise testing was to survey the interior and wayside noise levels of the ACT-1 vehicles in both the high- and low-density configurations in order to assess the acoustic environment of the passenger inside the cars, as well as the contributions of the Advanced Concept Train to community noise.

6.3 PROCEDURES

The test procedures used for the noise surveys were those outlined by the General Vehicle Test Plan for Urban Rail Transit Cars (report no. UMTA-MA-06-0025-75-14, September 1975). The following test sets were used for this program: Effect of Speed, Wayside Noise; Equipment Noise Survey, Wayside; Acceleration, Wayside; Deceleration, Wayside; Effect of Speed, On Car; Effect of Track Section, On Car; Interior Noise Survey.

6.4 TEST SITE

The ACT-1 acoustic surveys were conducted at the Transportation Test Center (TTC) facility as described in Section 1.3.3.2.

6.4.1 Static Survey

The interior and wayside static noise survey of the low-density car (DOTX-4) was performed with the car parked on the north spur outside the Transit Maintenance Building (TMB). Except for the ground plane, no reflecting surfaces affected the data.

The interior and wayside static noise survey of the high-density car (DOTX-5) was performed with the car parked at approximately station 369 on the transit test track (TTT).

6.4.2 Speed Survey

All wayside constant-speed, acceleration, and deceleration passby testing was conducted at station 369, as shown in Figure 4-42. Wayside noise was measured 50 feet from the track centerline.

The interior noise surveys for acceleration, deceleration, constant speed, and speed effect were conducted through track Section IV as shown in Figure 4-42. A survey to evaluate the effect of track section on interior noise was conducted by traversing the complete track oval as shown in Figure 4-42.

6.5 INSTRUMENTATION

A portable microphone/recorder data system was used to survey both interior and wayside noise levels of the ACT-1 cars. The instrumentation consisted of a 1-inch condenser microphone and a ¼-inch magnetic tape recorder. Figure 6-1 presents a block diagram of the data acquisition system and Figure 6-2 the data reduction system for this program. A sound-level meter was used to document A-weighted sound levels during the conduct of each test. In all instances, however, the levels presented in this report represent a long-term average of tape-recorded noise levels, rather than sound-level-meter readings.

6.5.1 Calibration

The recorders were calibrated prior to testing with a swept-frequency sinusoidal-insert voltage over the range from 20 Hz to 20 kHz. The entire record/produce system frequency response, including the microphone, was evaluated during this calibration, with the microphone diaphragm actuated electrostatically. During field tests, a known signal (eg, 94 dB at 1,000 Hz) was recorded on each tape, generally at the beginning and end, to establish system sensitivity and a reference level.

6.5.2 System Accuracy

The noise-recording system had an electrical frequency response linearity as shown in Figure 6-3 for a range of signal voltage levels corresponding to input sound levels of 50 dB to 120 dB at the microphone. Compensation for system nonlinearity was included for all data reduction procedures.

The total harmonic distortion of the noise measurement and recording equipment as an assembly did not exceed 4 percent over the measurement dynamic range.

The Boeing Vertol Company operates a calibration/certification laboratory to insure maintenance of instrumentation standards traceable to the National Bureau of Standards. Analyzer characteristics such as filter bandwidths and microphone calibrators are checked twice yearly. Frequency response characteristics of recording systems are determined prior to each test program.

6.6 DATA REDUCTION

The basic analysis of all data recorded during the program consists of a frequency analysis using an A-weighting filter. For reduction of data where a graphic level recorder was used, such as wayside and interior time histories, the level recorder was set at control positions which reproduced sound-level-meter readings set on the slow scale unless otherwise noted. For wayside passbys, the reported data was read directly from a sound-level meter on site.

All steady-state data points have been analyzed using realtime digital processing and are presented as one-third-octave band and, occasionally, narrowband spectra. The data presented in third-octave spectra represent rms levels which have been integrated over sampling times of at least 8 seconds unless otherwise noted. Narrowband spectra have been determined generally from 32 data samples. The number of data samples is presented on each chart. The length of each data sample is a function of the frequency range of the analyzer and is ½ second for a 0 to 1,000-Hz range. For 32 samples, the total analysis time is 16 seconds.

Where one-third-octave band analyses were performed, the A-weighted level was determined by the analyzer during the same processing time. Therefore, all steady-state A-weighted sound levels reported correspond to the identical sampling periods as for one-third-octave analysis.

6.7 ACT-1 CARS ACOUSTIC FEATURES

The ACT-1 cars have been defined in Section 2.0. Those design features which affect the acoustic quality are summarized below.

Two cars were constructed representing low-density and high-density seating arrangements as shown in Figure 2-2. Seating in the high-density car comprises rigid fiberglass units allowing for 36 seats and 32 supports. The low-density car, on the other hand, represents an arrangement of upholstered seats designed for a seating capacity of 56 passengers with a nominal capacity of 96. The floor and kickpads of both cars are carpeted, as are partial areas of the windscreen. The low-density seating, however, achieves additional absorption in the low-density car interior which is not provided by the molded fiberglass seats of the high-density car. No absorption testing of the car interiors was conducted, however.

The general arrangement of undercar equipment is shown in Figure 2-5. There are two energy storage units per car and the systems are separate. The ESU's operate independently, but due to manufacturing tolerances, ESU speeds at any instant in time are similar but not identical. This frequently results in the production of acoustic beating, the period randomly varying as the phasing between units varies. The impact which this beating has on the passenger environment is discussed in Section 6.9, Interior Noise.

The floor of the ACT-1 cars contains significant amounts of acoustical treatment in order to reduce the transmission of undercar noise. The region immediately above the ESU's includes a barrier with a surface density of 4.7 lb/ft^2 over the floor between the forward and rear doors, and to 2 lb/ft^2 beyond the area (see Figure 6-4). In addition, a general damping treatment was applied to the interior surfaces of the ESU enclosure to reduce wayside noise levels. Clearance between the ESU and the enclosure did not allow application of any other acoustical materials. Cross-sectional views of the floor for three representative car locations are illustrated in Figure 6-4.

The ACT-1 vehicles included grooves for damping rings on the inner and outer face of each running wheel. The purpose of these rings is to reduce wheel squeal on short-radius curves. There is evidence from testing on other transit cars that wheel damping also reduces passby noise on tangent track by 1 to 2 dBA. The test facility at the transportation test center at Pueblo, however, does not include a screech loop to evaluate wheel squeal and the damping rings were not installed for any testing at TTC.

6.8 COMMUNITY NOISE

6.8.1 Test Description

Wayside noise testing was conducted for both passby and car static conditions. For steady-speed passbys, testing was conducted at station 369 as described in Section 6.4. The microphone was positioned 50 feet from the track centerline at a height of 5 feet above local ground level. The diaphragm was oriented for 90-degree or grazing incidence for passby noise. A windscreen was installed on the microphone, although winds were below 5 mph for all testing. For acceleration and deceleration surveys, testing was conducted at station 380 so that a reference point (boarding platform) could be used to initiate test sequences.

The survey of the low-density car, DOTX-4, with the car static was conducted outside the transit maintenance building. Records of equipment noise were taken at both 15 feet and 50 feet from track centerline at the midpoint of the test vehicle on the left side.

Testing of the high-density car, DOTX-5, with the car static was conducted on the test oval at station 369 on both sides of the car at a distance of 50 feet.

Figure 6-5 shows wayside passby noise at a distance of 50 feet from the track centerline. With the car static, noise arises predominantly from the energy storage unit (ESU) and is related to ESU speed as shown in Figure 6-6. Total car noise during passby is composed of wheel-rail and equipment noise sources. Subtracting ESU levels (the major equipment source) as determined from Figures 6-5 and 6-6 gives an estimate of the contribution of wheel-rail noise to the total signature (Figure 6-5).

Figure 6-6 shows the speed of the energy storage unit as a function of car speed. Although ESU speed can vary over a broad range, it generally lies in the envelope shown which results from the load demand of the propulsion system.

Wayside noise levels of the ACT-1 car are compared with other recent rail transit vehicles in Figure 6-7. Each of the vehicles shown had air-conditioning systems and had all items of equipment operating for the noise survey. Vehicle configurations during the noise survey for each car are shown in Table 6-I.

TABLE 6–I. VEHICLE CONFIGURATIONS DURING NOISE TESTING

Vehicle	No. of Cars	No. of Bogies	Wheel Type	Wheel Damping
Act 1	1	2	Aluminum center	None
SOAC	1	2	Monobloc steel	None
CTA2400	2	4	Aluminum center	Ring-damped
SLRV	1	3	Acousta Flex	Resilient

Wayside noise levels are presented in tabular form for all ACT-1 tests conducted at Pueblo in Tables 6-II, 6-III, and 6-IV for speed effect, acceleration, and deceleration, respectively. The ESU speed is included in this information where it is available.

6.8.2 Acceleration/Deceleration Testing

In general, noise levels during both accelerating and decelerating passbys display lower amplitudes on the A-weighted scale than the steady passby records, with the decelerating car having the lower noise signature. At high speeds during deceleration (60 mph) the ACT-1 car is 4 or 5 dBA quieter than steady-speed passbys. The accelerating car appears to be 0 to 2 dBA quieter at the same speed.

6.9 INTERIOR NOISE

6.9.1 Test Description

Interior noise levels were surveyed in both ACT-1 cars for locations which represent both seated and standing passengers. For the basic survey, noise levels were measured in the cab (station 55), at the centers of the forward module (station 218), center module (station 491), and rear module (station 764). For the detailed survey at 60 mph, seven locations representing both standing and seated passengers were surveyed. Tape-recorded levels were verified by sound-level-meter readings taken during the same time intervals under the same operating conditions.

6.9.2 Effect of Speed

Noise levels in the high- and low-density car are shown in Figure 6-8 as a function of car speed and are compared with the goal established for these cars. Note that, unlike other transporation vehicles, the ACT-1 car interior noise displays an initial trend of decreasing noise as car speed increases. This results from reductions in ESU speed, initially 90 to 97 percent while the car is static, decreasing as the car speed increases, with the ESU at minimum rpm for car speeds of 20 to 40 mph. Wheel-rail noise in this speed regime does not substantially contribute to the overall noise within the car. As speeds increase over 40 mph, both ESU speed and wheel-rail

TABLE 6–II. WAYSIDE NOISE (SPEED EFFECT)

Car	Car Speed (mph)	ESU Speed (%)	Equipment Operating	Micr Loc	Dir of Travel	Car Side Facing Micr	Weighted Sound Level (dBA)
			Ambient	50 ft outside of loop	Car static		38-43
DOTX-5	0	75	ESU's only			Left	69
		75	Vent fan on				70
		75	T/C on				71
		90	ESU's only				73
		90	Vent fan on				73
		90	T/C on				73.5
		97.5	ESU's only				76
		97.5	Vent fan on				75
	0	97.5	T/C on				77
	20		All systems on	50 ft outside of loop	N		72.5
	40				N		76
	60				N		78
	60				S		78
	80				N	Left	79
	0	97.5		50 ft inside loop		Right	78
	20				N		72.5
	40				S		76
	60				N		78
DOTX-5	80		All systems on	50 ft inside loop	N	Right	82

TABLE 6–II – Continued

Car	Car Speed (mph)	ESU Speed (%)	Equipment Operating	Micr Loc	Dir of Travel	Car Side Facing Micr	Weighted Sound Level (dBA)
DOTX-4	0	70	Emergency vent fan	50 ft		Left	38
			2 ESU's				68
			2 ESU's + right T/C				68
			2 ESU's + left T/C				67
			2 ESU's + 2 T/C's				72
			2 ESU's + 2 air comf fans	50 ft			71
			Emergency vent fan	5 ft			42
			2 ESU's				75
			2 ESU's + right T/C				80
			2 ESU's + left T/C				73
			2 ESU's + 2 T/C's				83
			2 ESU's + 2 air comf fans	5 ft			81
		70	ESU's only	50 ft			68
		85	ESU's only				69
		95	ESU's only				72-73
		70	All systems on				71
		85	All systems on				72
DOTX-4	0	95	All systems on	50 ft		Left	73

TABLE 6–III. WAYSIDE NOISE (ACCELERATION)

Car	ESU Speed at Start of Run (%)	Start Point Before Passing Micr (ft)	Car Speed Past Micr (mph)	Accel Rate P-Wire (%)	Direction of Travel	Micr Location	Weighted Sound Level (dBA)
DOTX-5	97.5	0	0	100	N	50 ft	74
							72 Repeat
	97.5	500	40	100			74
							74 Repeat
	97.5	1,000	53	100			76
							76.5 Repeat
	97.5	2,000	67.5	100	N	50 ft	78.5
							76 Repeat

TABLE 6-IV. WAYSIDE NOISE (DECELERATION)

Car	ESU Speed at Start of Run (%)	Entry Point Prior to Deceler (ft)	Car Speed Past Micr (mph)	Decel Rate (%)	Micr Location	Weighted Sound Level (dBA) Blended Braking	Weighted Sound Level (dBA) Friction Braking
DOTX-5		50	80	100	50 ft	79	
		150	80				77
		500	70			77.5	77.5
		1,000	52			76	75.5
		1,500	29	100		76	72.5
		1,000	58	50		77.5	
		1,000	61	50	50 ft		76.5

noise increase up to car velocities of 50 mph. Above this speed in the low-density car, the ESU tended to stabilize, and interior noise followed this same trend. Where the ESU speeds continued to increase in the high-vehicle-speed region (DOTX-5), the interior noise levels also increase.

Figure 6-9 presents the 1/3-octave spectra at the midcar location for five car speeds. The ESU flywheel rotational frequency can be noted in the spectra for each car speed. This frequency is contained in the 1/3-octave bands centered at either 125 Hz or 160 Hz. The second harmonic of ESU rotational speed is sometimes present in the spectra as well.

Noise levels vary throughout the car, with the operator's location in the cab displaying the lowest level and the center of the car, which is midway between the ESU's, generally exhibiting the highest noise level. This is illustrated in Figure 6-10 which shows 1/3-octave frequency spectra at four representative locations throughout the car at a speed of 60 mph. The range in A-weighted noise is 11 dBA, with the cab at 64 dBA and the midcar location displaying 75 dBA.

A survey of interior noise was conducted with the car static for ESU speeds of 75, 88, and 97.5 percent. For each ESU speed, the contribution of auxiliary systems to interior noise was also determined. The results of this survey are shown in Figures 6-11 through 6-13. These illustrations also show that the center modules of the car display the highest sound levels.

Interior noise levels at 60 mph are shown in Figure 6-14 for both the high-density and low-density cars. Differences in levels between the cars result from unequal speed of the energy storage units, changes in interior trim between cars, differences in auxiliary equipment operating at the time of the survey, and variations in the acoustic power radiated by ESU's even though the units are otherwise identical. Not shown in any of these illustrations is the effect of acoustic beating of the two energy storage units at the flywheel rotational speed. The units operate at similar rotational speeds, but are not synchrophased with each other. The small variations in rotational speed which occur randomly with time sometimes result in large-amplitude sound level variations in the center module of the cars. In the corner seat of the center module (rearmost section), for example, at a speed of 60 mph and with the vent fans operating (no turbocompressors), the variation in sound level is 9 dBA (see Figure 6-15). The illustration also shows that other locations, representing a majority of seat locations in the car, do not display beating, which occurs primarily in the center module. The level reported in Table 6-V as representative of location 1 of Figure 6-15 is 74 dBA, the average value for this time interval.

The ESU flywheel frequency varies between 180 Hz at 100-percent rotational speed to 135 Hz at 75-percent rotational speed, and its amplitude may be 20 to 25 dB above the spectrum level in this frequency region. Figure 6-16 illustrates the major contribution of the energy storage unit noise to ACT-1 interior noise levels. Even when A-weighted, the spectra show the flywheel 1/rev frequency dominating the acoustic spectra of the ACT-1 cars.

All interior data is presented in tabular form in Tables 6-V, 6-VI, and 6-VII, the equipment noise survey for a static car, the vehicle survey at 60 mph, and the effect of speed, respectively.

Interior noise levels of the ACT-1 cars are compared with some other recent transit vehicles in Figure 6-17. The A-weighted levels of the ACT-1 cars are similar to those of SOAC and the CTA2400 series cars at speeds of 60 mph and above. At lower speeds where ACT-1 sound levels are somewhat higher than these other vehicles, the energy storage units establish the noise level in the car.

Noise levels were recorded in the low-density car (DOTX-4) during accelerating and decelerating conditions. Records were taken at station 218 (forward module) and station 491 (center module) for 50-percent and 100-percent acceleration and deceleration rates. Figure 6-18 presents the A-weighted time histories of an accelerating car and Figure 6-19 illustrates interior noise of a decelerating car. The records show that interior noise under these conditions is similar to that of the car during steady-speed conditions, for the same vehicle speed/flywheel speed settings.

6.10 NOISE SOURCES

Analysis of sound levels measured on the ACT-1 cars identified several items of undercar equipment contributing to the interior noise signature. However, the energy storage units and turbocompressor establish the A-weighted sound level in the car.

- Equipment Noise Sources
  - Energy storage units (ESU)
    - Flywheel
    - Motor
    - Alternator
    - ESU gearbox unit
  - Turbocompressor
  - Recirculation fan (vent fan)
  - Brake compressor
  - The ESU and turbocompressor

In addition to these sources of noise, excitation of the vehicle structure itself can contribute to interior noise. Analysis of recorded data identified a response at the bending frequency of the ESU/motor assembly (110 Hz). Figure 6-20 is a narrowband spectrum of interior noise at an ESU speed of 97.5 percent, illustrating that this source can be a major contributor to overall interior noise levels when a forcing frequency approaches the natural frequency of the structure.

An investigation was conducted to determine the relative contribution of the energy storage units to airborne and structureborne noise of the car. The approach was to totally decouple the ESU from the carbody structure to obtain sound levels due to the airborne path only. The results of this testing showed that the sound level directly above the ESU was reduced by

24 dBA when the unit was operated in place with all structureborne paths eliminated. As a result of this investigation, a floor-isolation system was installed to reduce the structureborne contribution of ESU noise. This isolation system was incorporated in the car for all noise tests reported in this document.

TABLE 6-V. INTERIOR NOISE, VEHICLE SURVEY AT 60 MPH

Car	Car Speed (mph)	ESU Speed (%)	Auxiliary Equipment Operating	Microphone Location Station, Seat Loc	Microphone Height STG – Standing SEL – Seated	Weighted Sound Level (dBA)
DOTX-4	60	77	Air comfort fans	55, cab	SEL	70
				90, left window	SEL	68
				130, left window	SEL	69
				130, left aisle	SEL	70
				130, centerline	STG	69
				130, right aisle	SEL	69
				130, right window	SEL	70
				218, left door	STG	75
				218, centerline	1 ft from ceiling	73
				218, centerline	STG, ear level	72
				218, centerline	1 ft from floor	72
				218, right door	STG	75
				250, left window	SEL	70
				290, left window	SEL	72
				290, left aisle	SEL	71
				290, centerline	STG	68
				290, right aisle	SEL	68
				290, right window	SEL	70
				330, left window	SEL	72
				365, left window	SEL	72
				365, left aisle	SEL	69
				365, right aisle	SEL	68
				365, right window	SEL	72
				410, left window	STG	76
				410, left seat	SEL	68
				440, left seat	SEL	69
				491, left door	STG	74
				491, centerline	1 ft from ceiling	70
				491, centerline	STG, ear level	71
				491, centerline	1 ft from floor	71
				491, right door	STG	73
				520, left seat	SEL	73
				560, left window	STG	73
				560, left seat	SEL	73
				600 left window	SEL	74
				640, left window	SEL	70
				680, left window	SEL	69

TABLE 6-V – Continued

Car	Car Speed (mph)	ESU Speed (%)	Auxiliary Equipment Operating	Microphone Location Station, Seat Loc	Microphone Height STG – Standing SEL – Seated	Weighted Sound Level (dBA)
DOTX-4	60	77	Air comfort fans	680, left aisle	SEL	67
				680, centerline	STG	68
				680, right aisle	SEL	70
				680, right window	SEL	71
				720, left window	SEL	65
				764, left door	STG	69
				764, centerline	1 ft from ceiling	70
				764, centerline	STG, ear level	68
				764, centerline	1 ft from floor	68
				805, left window	SEL	66
				840, left window	SEL	62
				840, left aisle	SEL	66
				840, centerline	STG	69
				840, right aisle	SEL	65
				840, right window	SEL	66
				(car sta, in.)		
DOTX-5	60	90	Air comfort fans, turbo-compressor	55	STG, ear level	
				75		69
				218		73
				235		73
				350		76
				350		77
				491		76
				510		80
				510		77
				625		74
				764		67
				775	STG, ear level	69
				75	SEL, ear level	69
				75		70
				235		73
				235		72
				350		72
				350		74
				510	SEL, ear level	72

TABLE 6-V – Continued

Car	Car Speed (mph)	ESU Speed (%)	Auxiliary Equipment Operating	Microphone Location (car sta, in.)	Microphone Height STG – Standing SEL – Seated	Weighted Sound Level (dBA)
DOTX-5	60	90	Air comfort fans, turbo-compressor	510	SEL, ear level	74
				625		73
				625		72
				775		70
				775	SEL, ear level	70

TABLE 6-VI. INTERIOR NOISE AND EQUIPMENT NOISE, STATIC CAR

Car	Car Speed (mph)	ESU Speed (%)	Auxiliary Equipment Operating	Microphone Location (car sta, in.)	Microphone Height	Weighted Sound Level (dBA)
DOTX-5	0	0	Background noise	55	STG, ear level	41
				218		41
				491		41
				764		42
		74	ESU's only	55		56
				218		62
				491		70
				764		70
		74	ESU's, air comf blowers	55		55
				218		63
				491		71
				764		67
		75	ESU's, air comf blowers, turbo-compressors	55		57
				218		66
				491		71
				764		68
		88.5	ESU's only	55		54
				218		65
				491		67
				764		68
		88.5	ESU's, air comf blowers	55		54
				218		66
				491		73
				764		67
		88.5	ESU's, air comf blowers, turbo-compressors	55		55
				218		66
				491		76
				764		68
		97.5	ESU's only	55		55
				218		65
				491		77
				764		76
		97.5	ESU's, air comf blowers	55		55
				218		71
				491		76
				764	STG, ear level	69

Car	Car Speed (mph)	ESU Speed (%)	Auxiliary Equipment Operating	Microphone Location (car sta, in.)	Microphone Height	Weighted Sound Level (dBA)
DOTX-5	0	97.5	ESU's, air comf blowers, turbo-compressors	55	STG, ear level	60
				218		69
				491		82
↓	↓	↓	↓	764	↓	83

TABLE 6-VII. EFFECT OF SPEED ON INTERIOR NOISE

Car	Car Speed (mph)	Auxiliary Equipment Operating	Microphone Location (car sta, in.)	Microphone Height	Weighted Sound Level (dBA)
DOTX-4	0	Air comfort fans	55	STG, ear level	60
			218		67
			491		70
			764		65
	15		55		64
			218		63
			491		68
			764		65
	25		55		64
			218		68
			491		71
			764		68
	35		55		66
			218		74
			491		74
			764		67
	50		55		64
			218		70
			491		72
			764		69
	60		55		67
			218		71
			491		71
			764		69
	70		55		67
			218		70
			491		69
			764		71
	78		55		69
			218		71
			491		70
			764		71

TABLE 6-VII – Continued

Car	Car Speed (mph)	Auxiliary Equipment Operating	Microphone Location (car sta, in.)	Microphone Height	Weighted Sound Level (dBA)
DOTX-5	0	T/C on	55	STG, ear level	55
			218		65
			491		74
			764		69
	20		55		52
			218		66
			491		68
			764		69
	40		55		59
			218		64
			491		71
			764		65
	60		55		64
			218		68
			491		75
			764		69
	80		55		66
			218		72
			491		77
			764		74

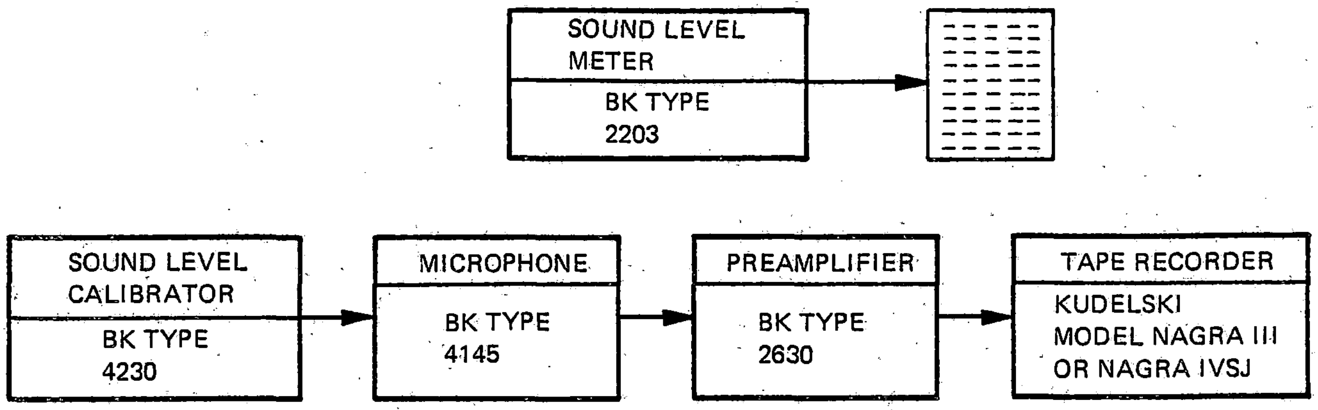


Figure 6–1. Acoustic Data Acquisition System

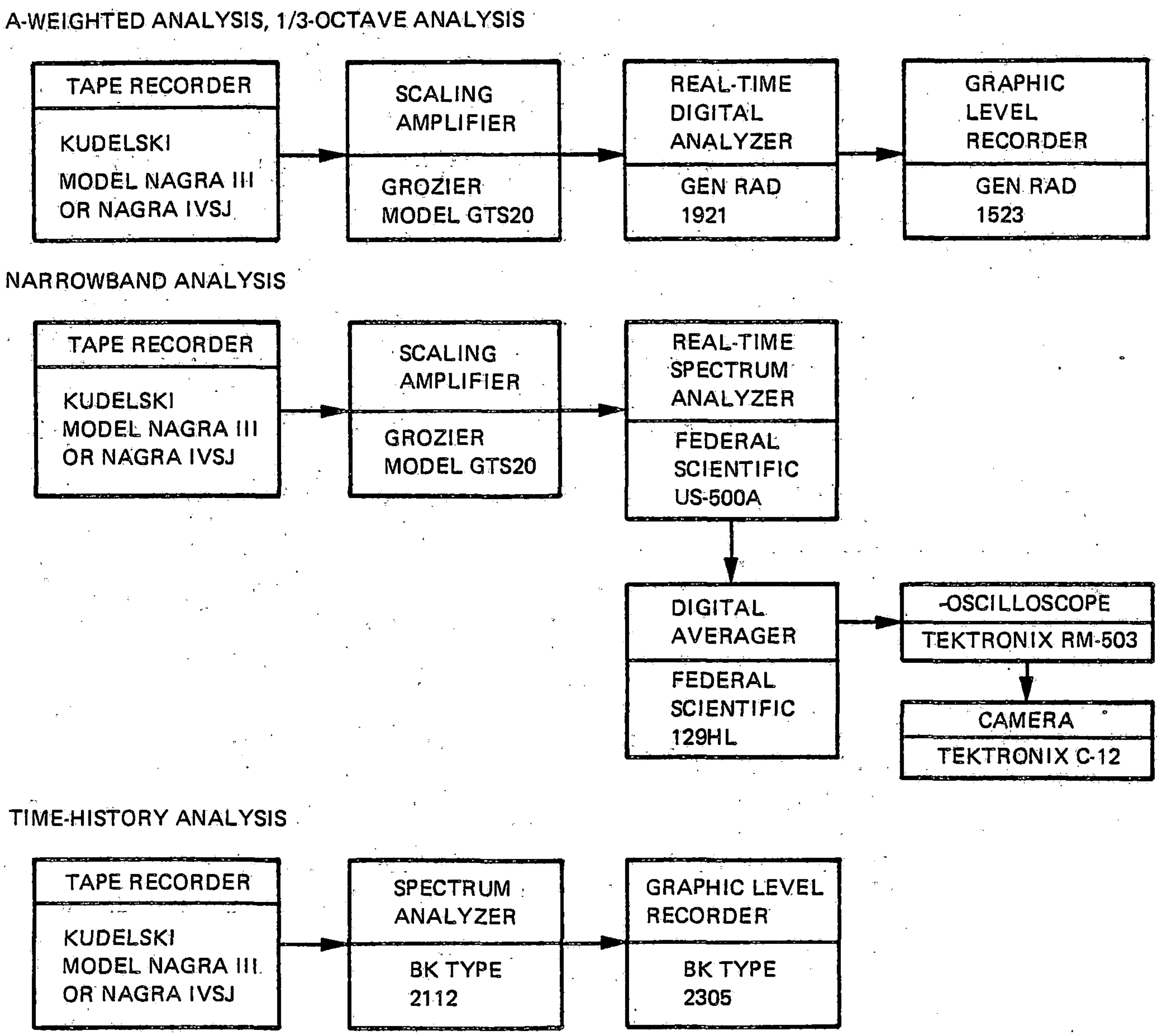


Figure 6–2. Acoustic Data Reduction System

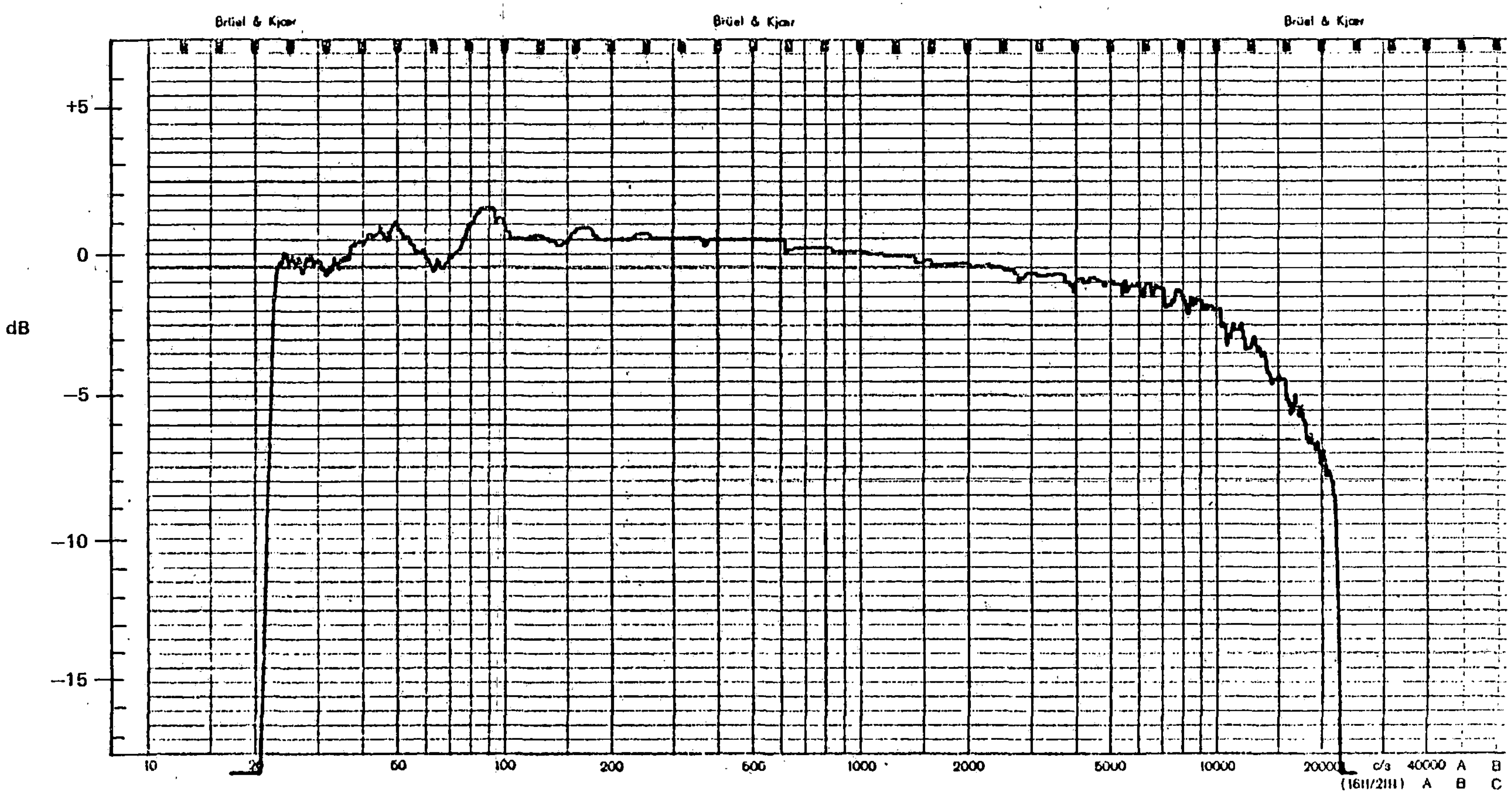


Figure 6–3. Record/Playback System Frequency Response

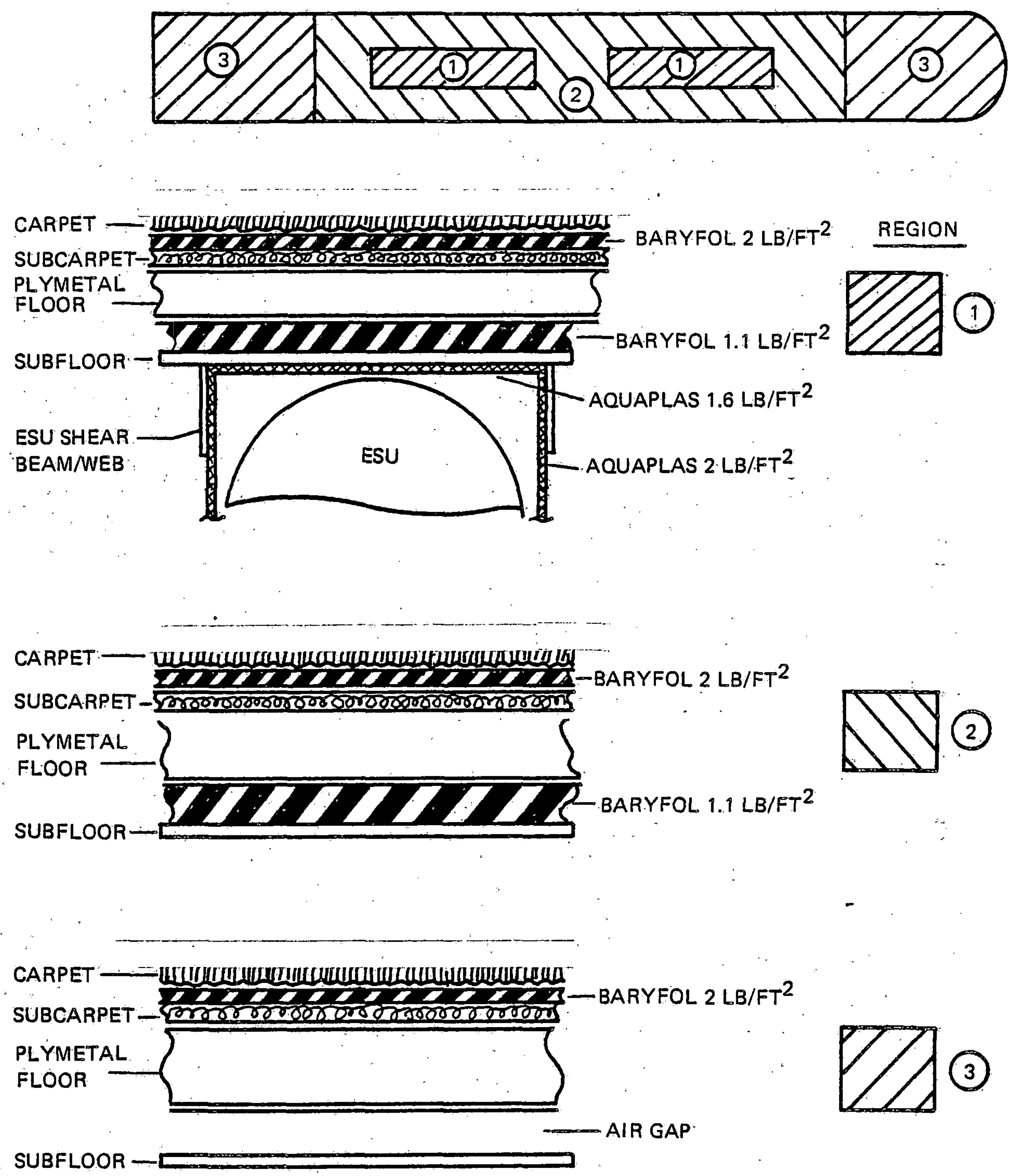


Figure 6–4. Representative Floor Construction

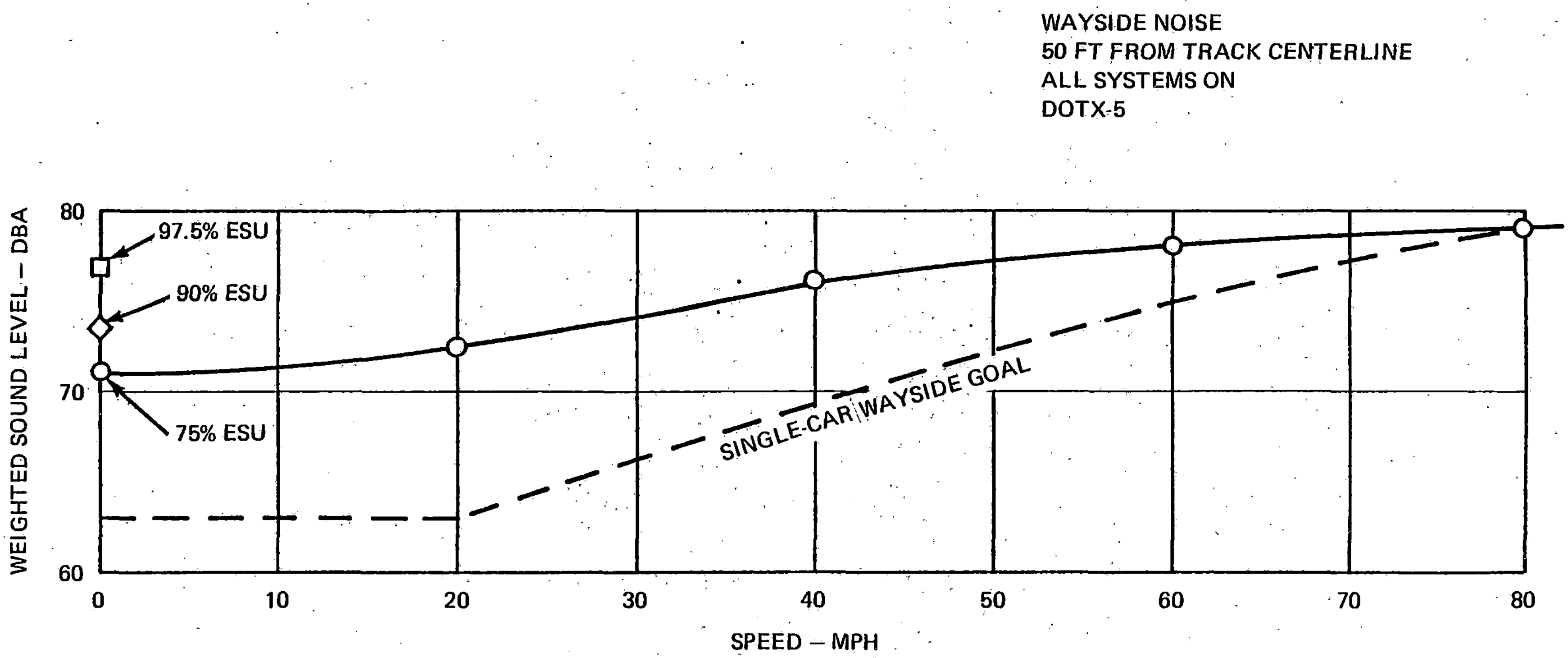


Figure 6–5. Effect of Speed on ACT-1 Wayside Noise

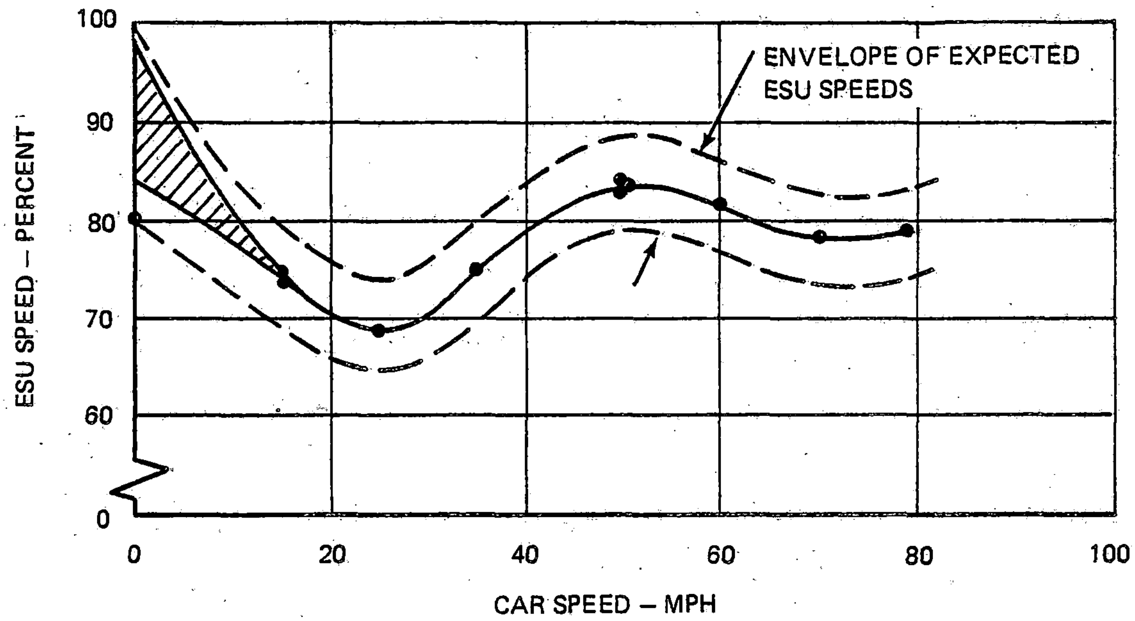


Figure 6–6. ESU Speed Trends With Car Speed

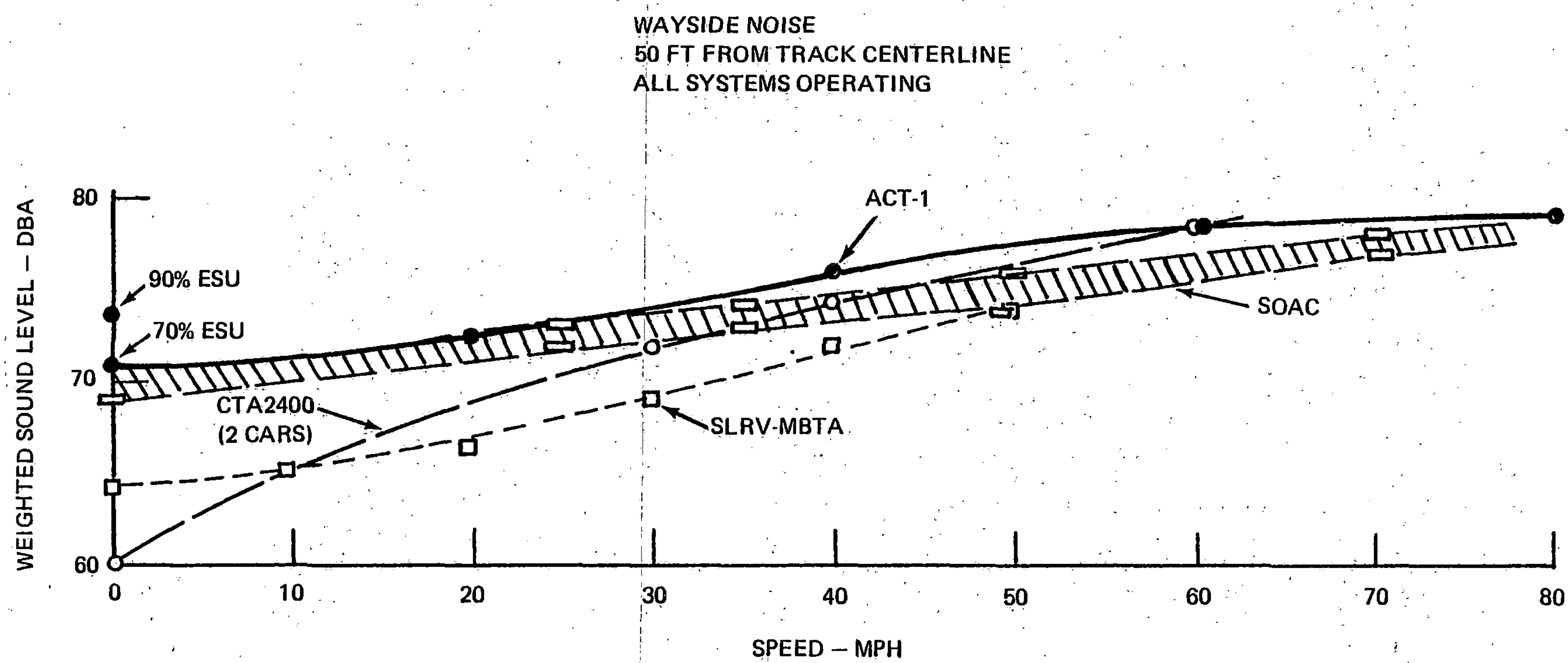


Figure 6–7. Comparison of ACT-1 Wayside Noise With Other Recent Rail Transit Vehicles

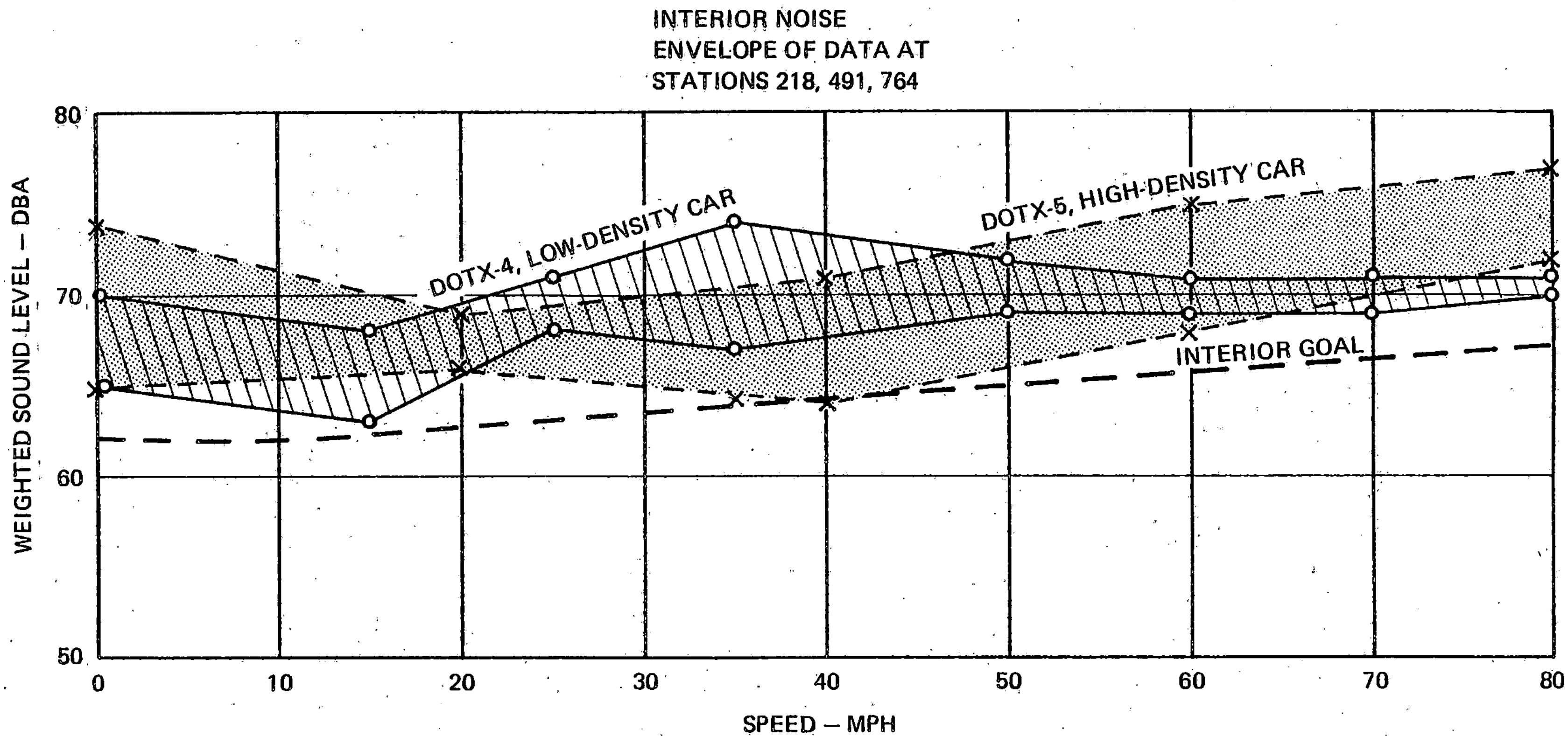


Figure 6–8. Effect of Speed on ACT-1 Interior Noise

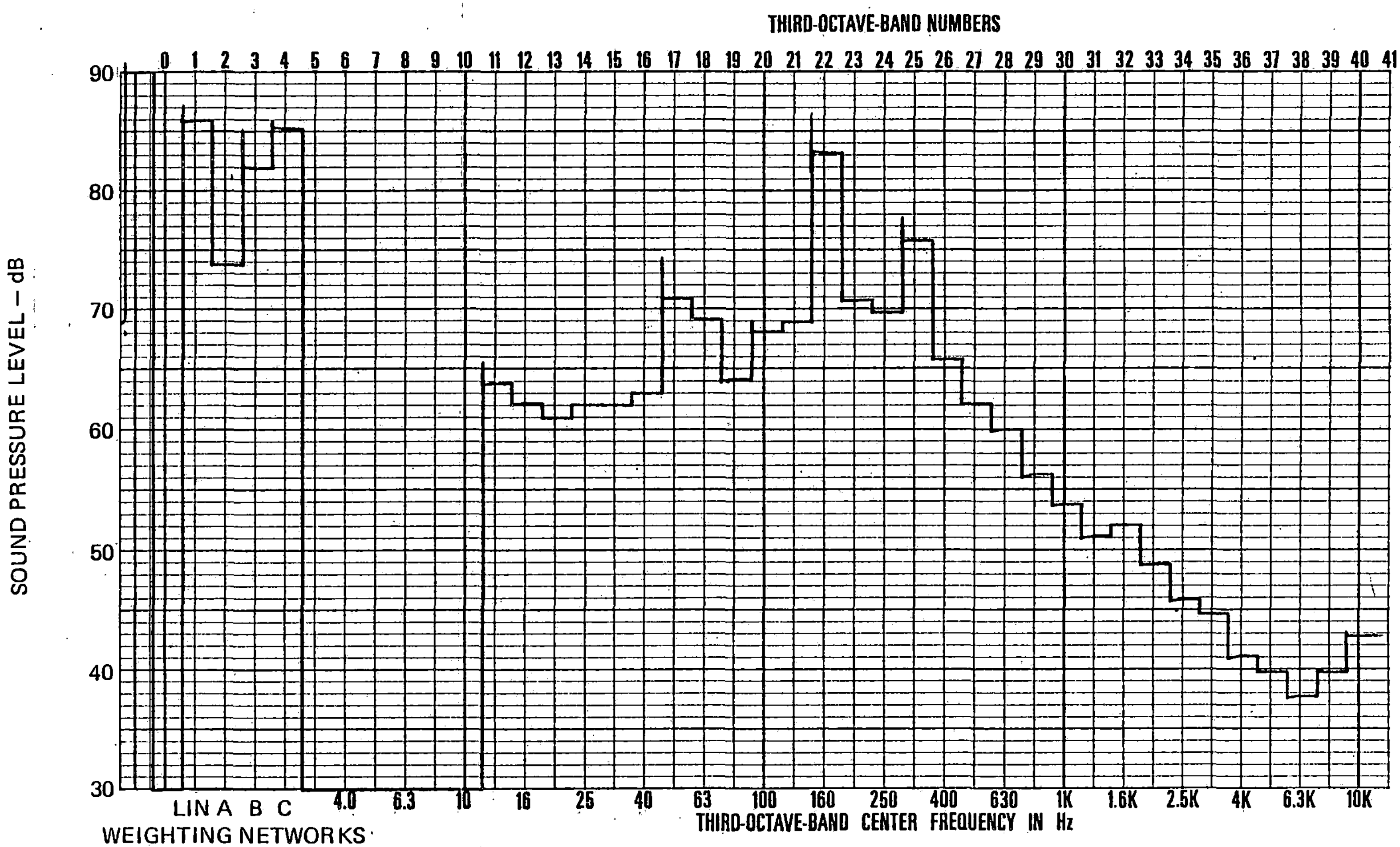


Figure 6–9. 1/3-Octave-Band Frequency Spectra of Midcar Interior Noise at Five Car Speeds
(Sheet 1 of 5) V = 0 MPH

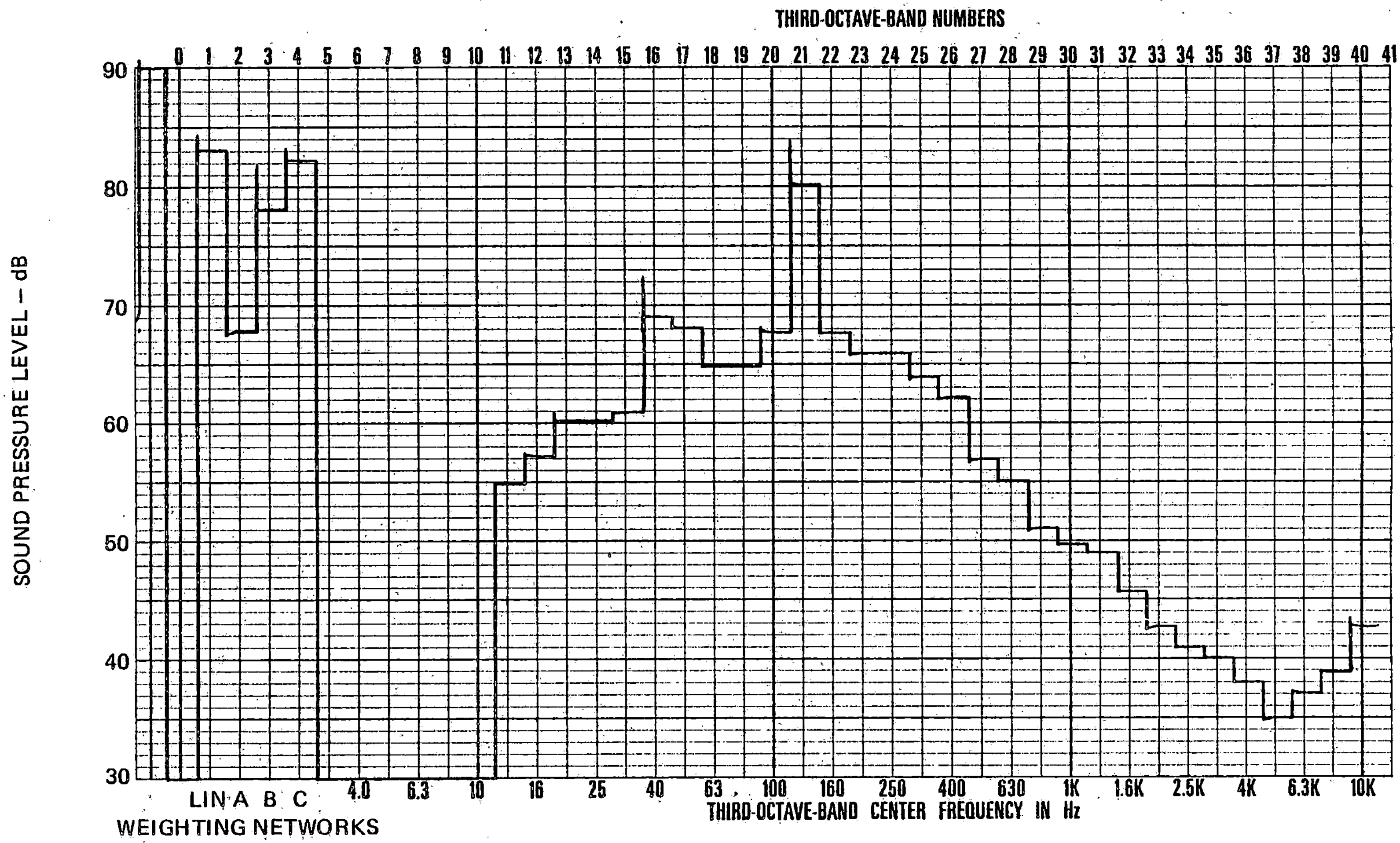


Figure 6–9. 1/3-Octave-Band Frequency Spectra of Midcar Interior Noise at Five Car Speeds
(Sheet 2 of 5) V = 20 MPH

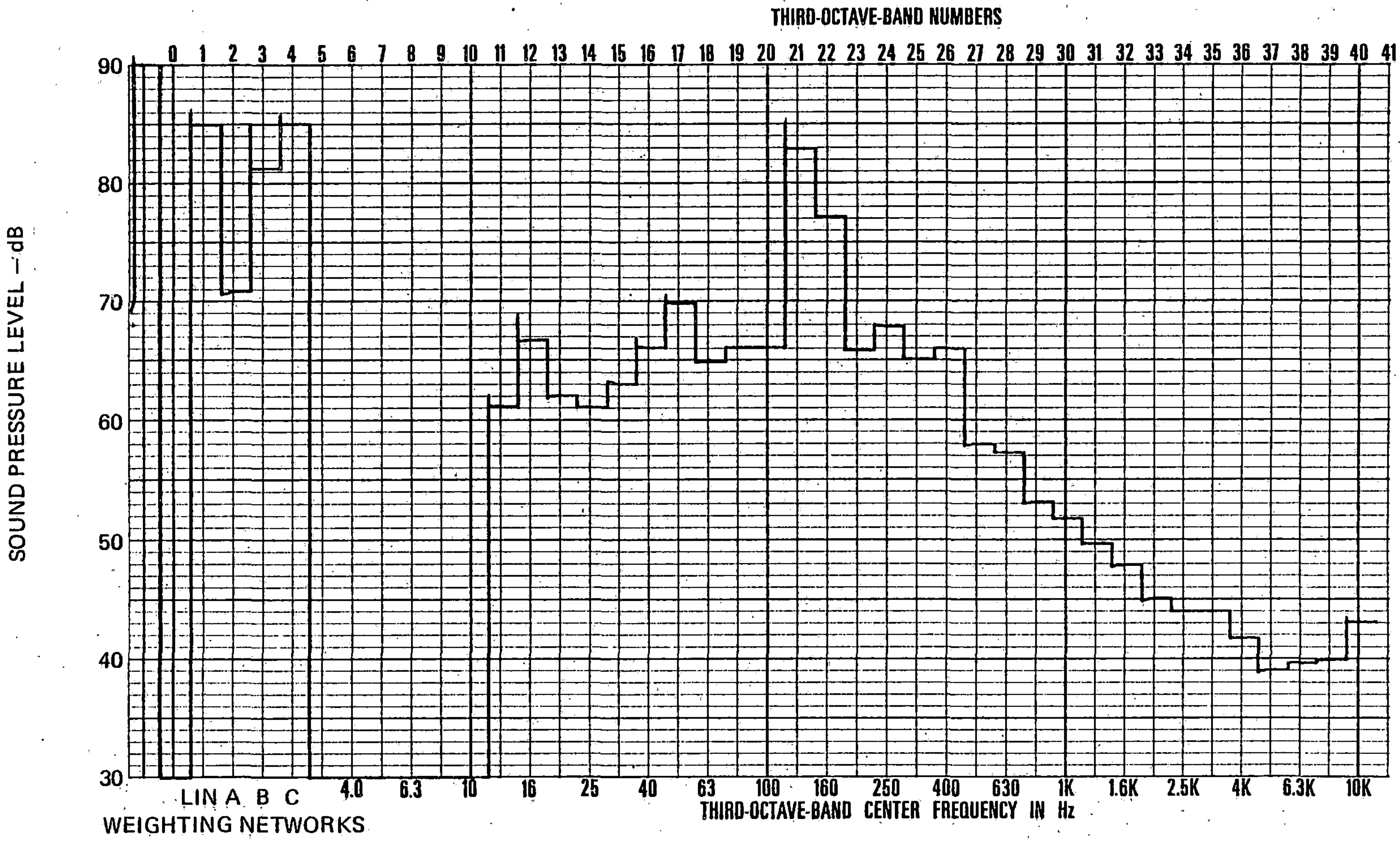


Figure 6–9. 1/3-Octave-Band Frequency Spectra of Midcar Interior Noise at Five Car Speeds (Sheet 3 of 5) V = 40 MPH

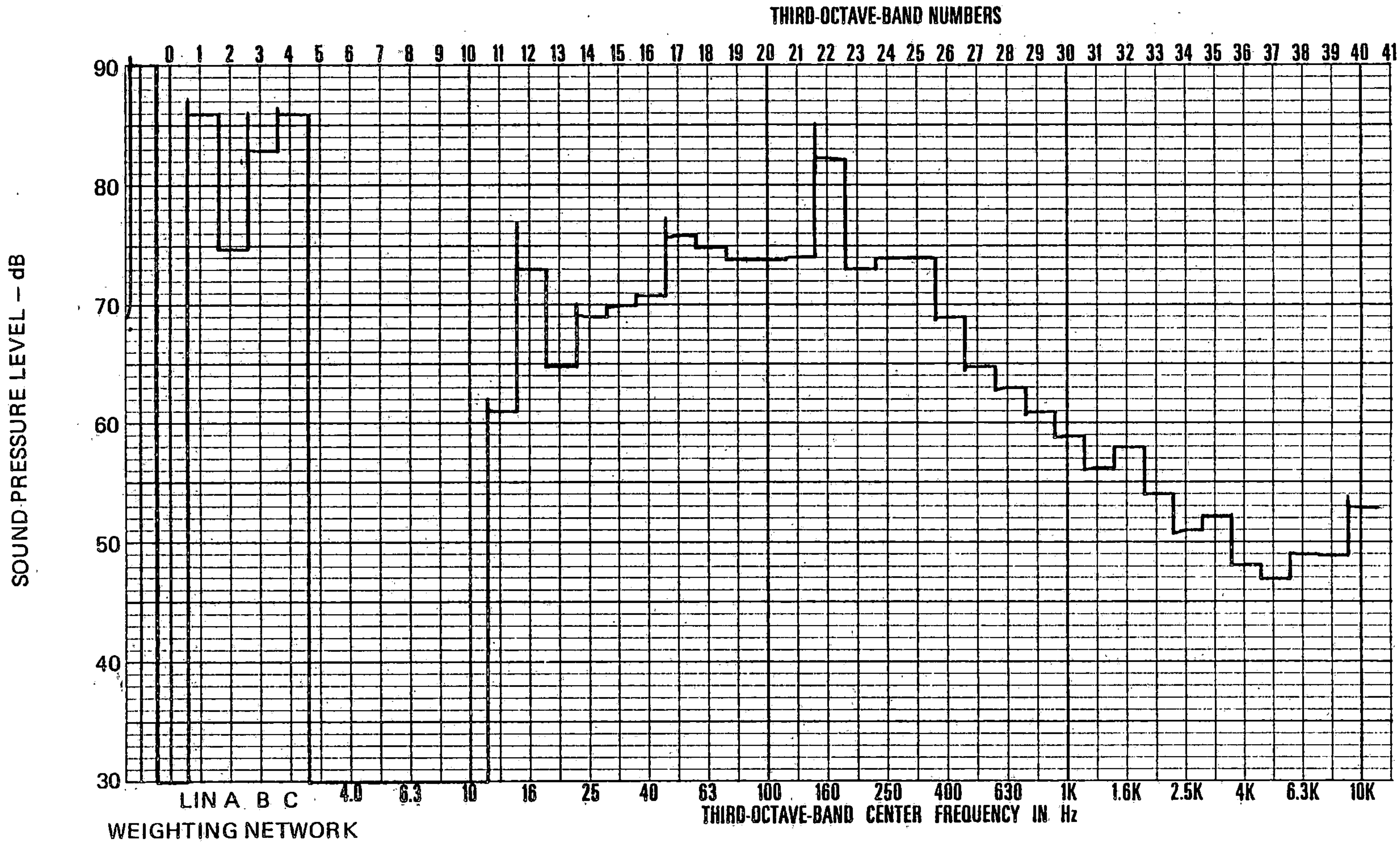


Figure 6–9. 1/3-Octave-Band Frequency Spectra of Midcar Interior Noise at Five Car Speeds
(Sheet 4 of 5) V = 60 MPH

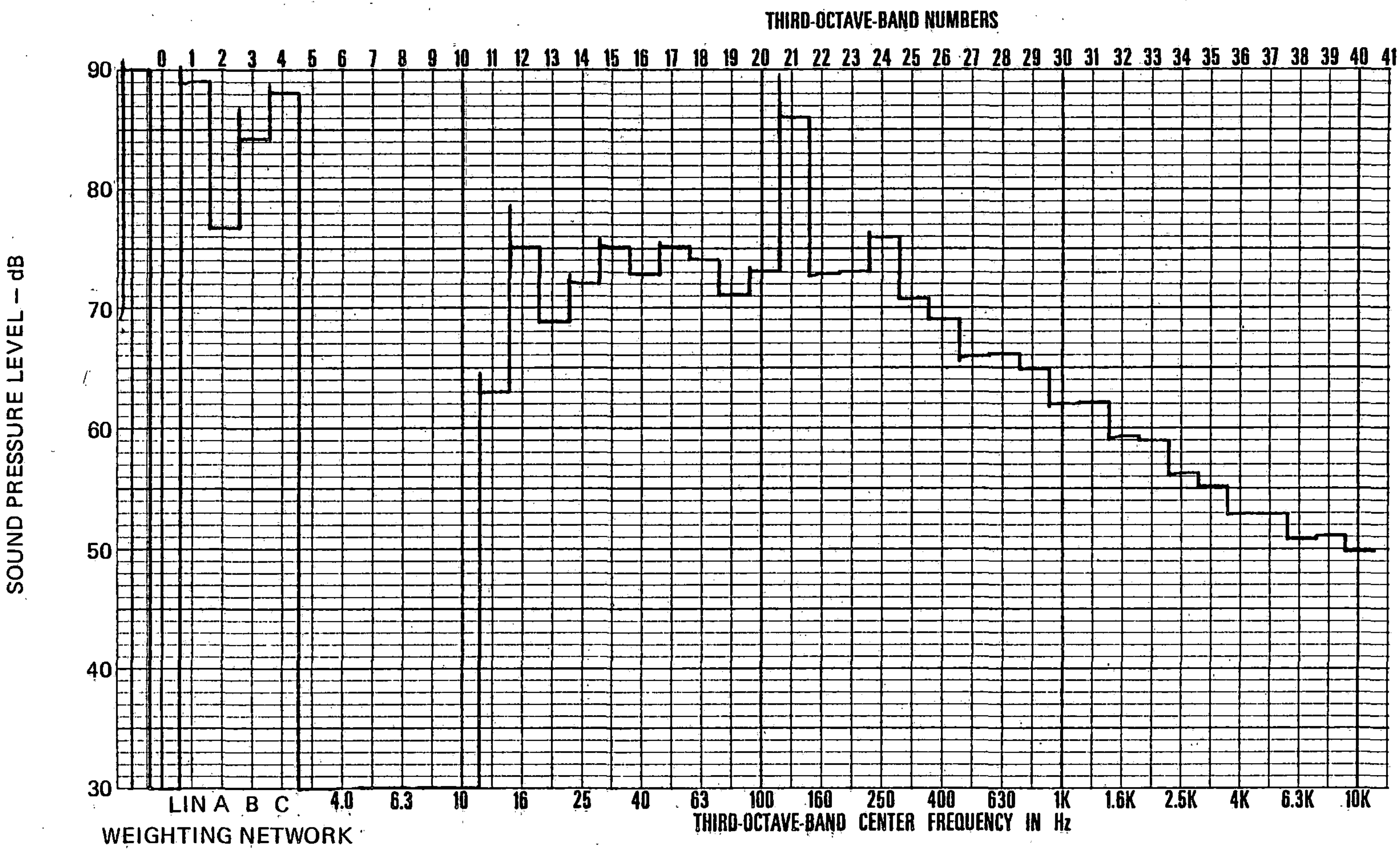


Figure 6–9. 1/3-Octave-Band Frequency Spectra of Midcar Interior Noise at Five Car Speeds (Sheet 5 of 5) V = 80 MPH

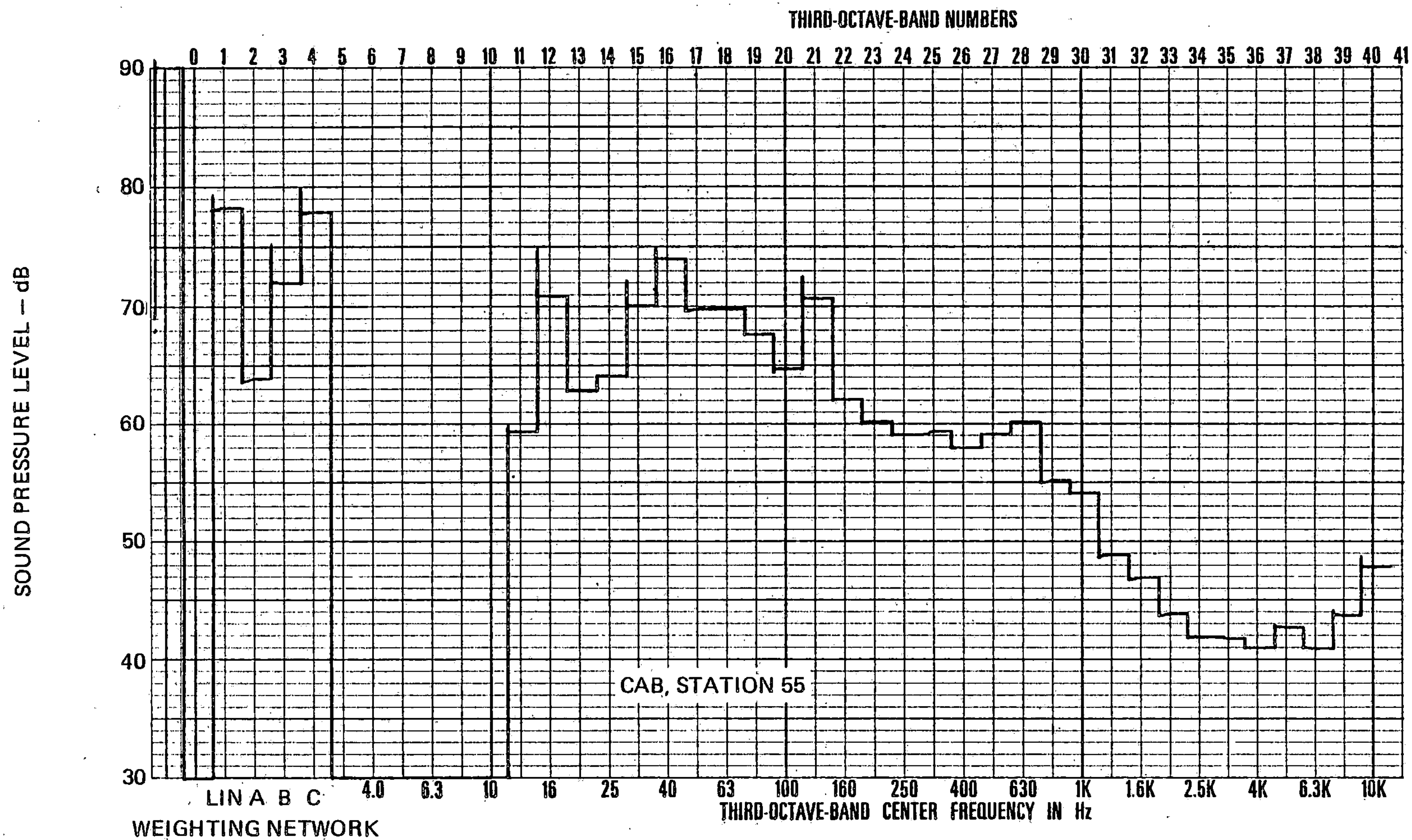


Figure 6–10. 1/3-Octave-Band Frequency Spectra at 60 MPH at Four Interior Locations (Sheet 1 of 4)

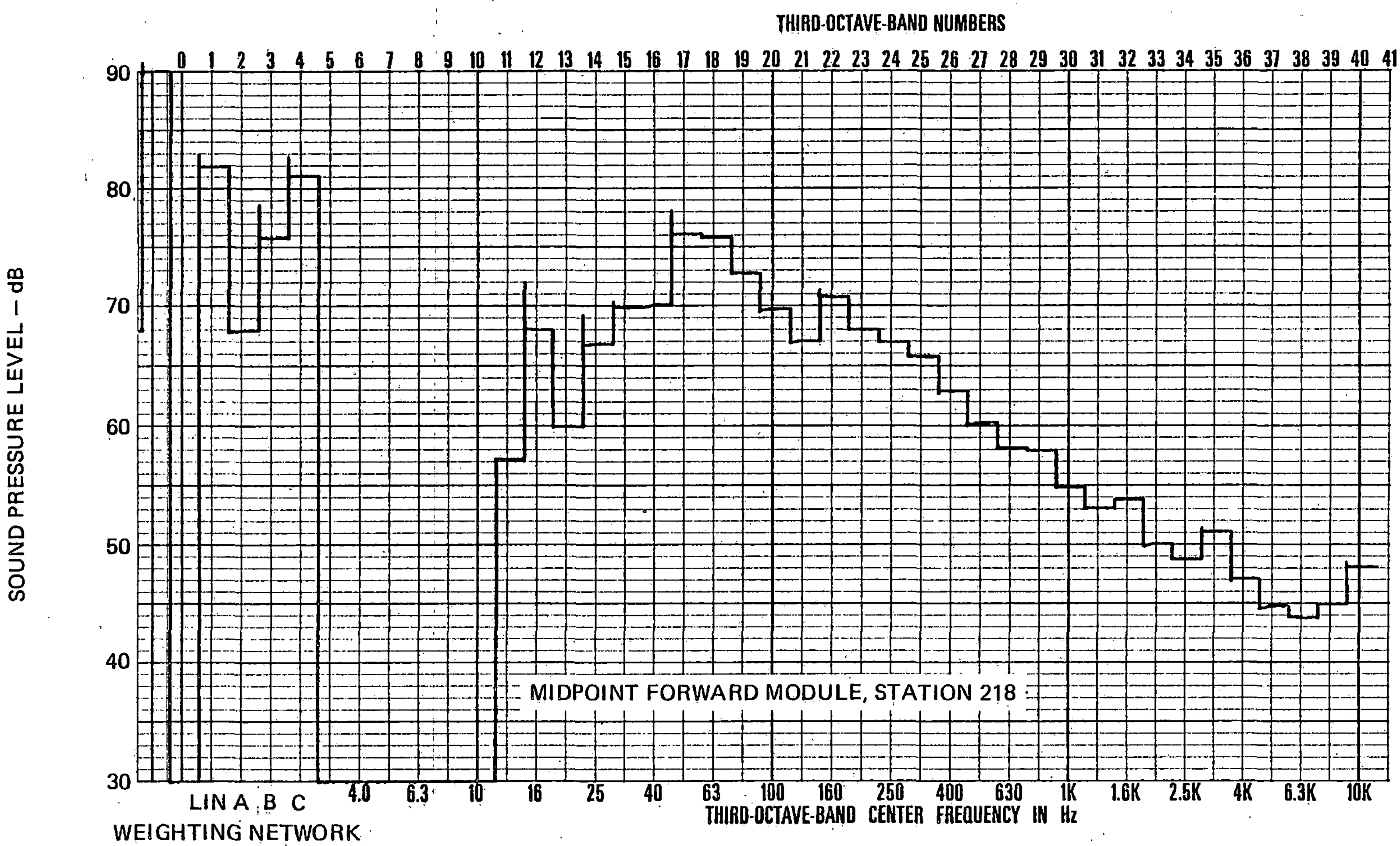


Figure 6–10. 1/3-Octave-Band Frequency Spectra at 60 MPH at Four Interior Locations (Sheet 2 of 4)

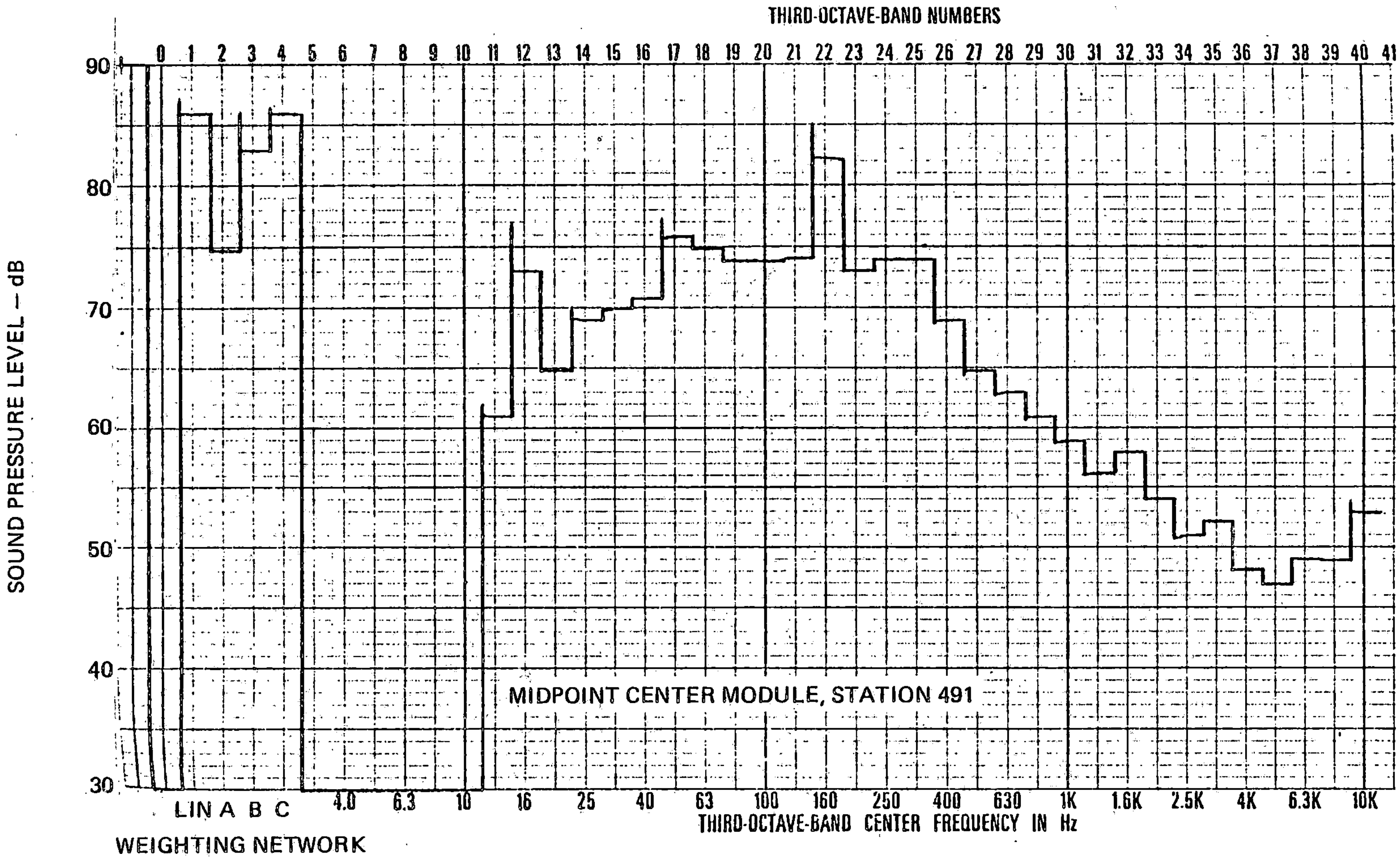


Figure 6—10. 1/3-Octave-Band Frequency Spectra at 60 MPH at Four Interior Locations
(Sheet 3 of 4)

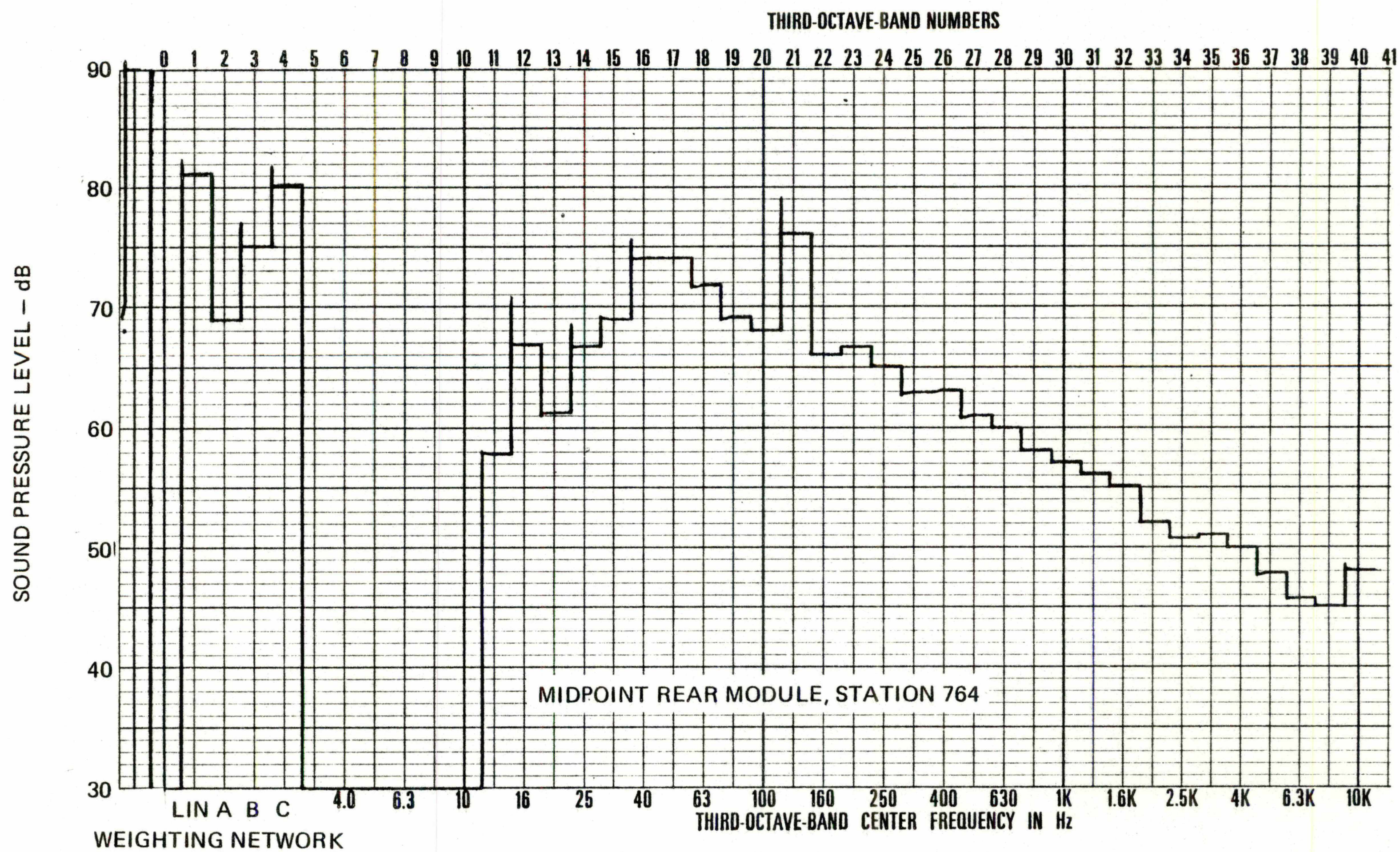


Figure 6–10. 1/3-Octave-Band Frequency Spectra at 60 MPH at Four Interior Locations (Sheet 4 of 4)

VENT FAN ON, TURBOCOMPRESSOR ON

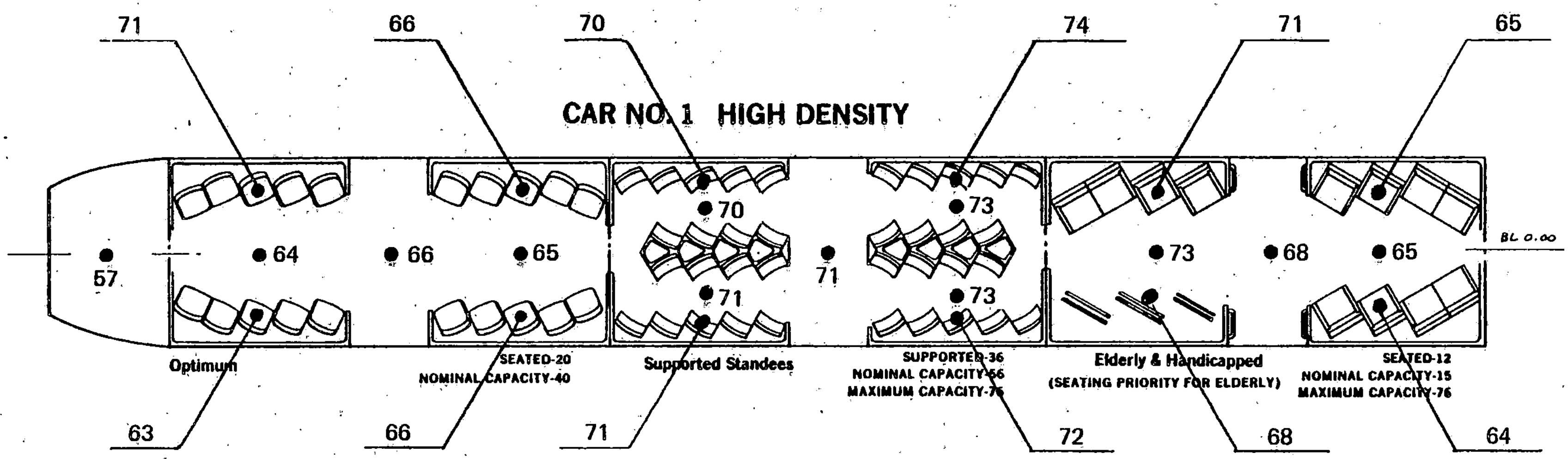


Figure 6–11. Interior Noise Levels With Car Static and ESU at 75 Percent

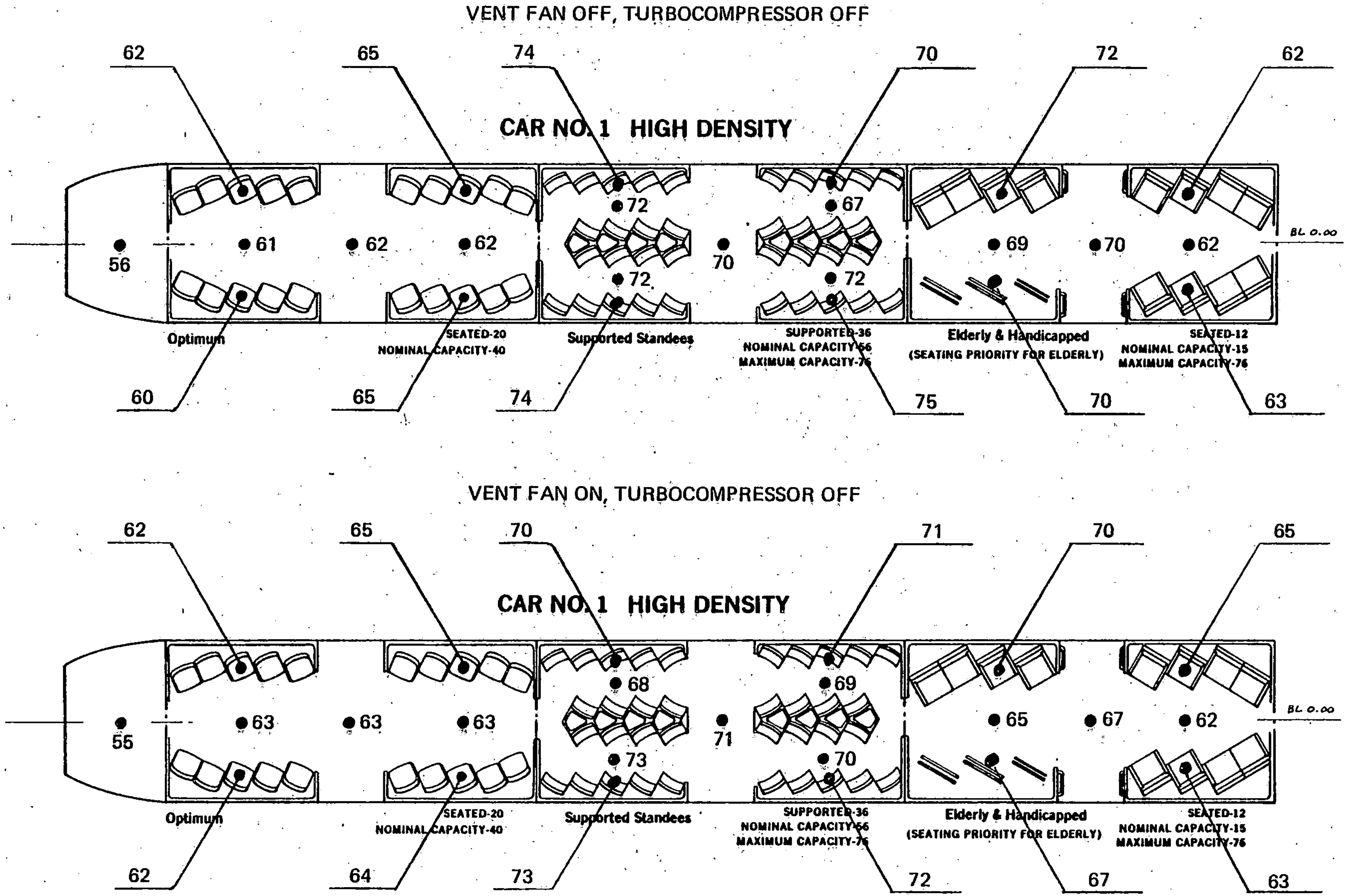


Figure 6–12. Interior Noise Levels With Car Static 75% ESU SPEED
(Sheet 1 of 3)

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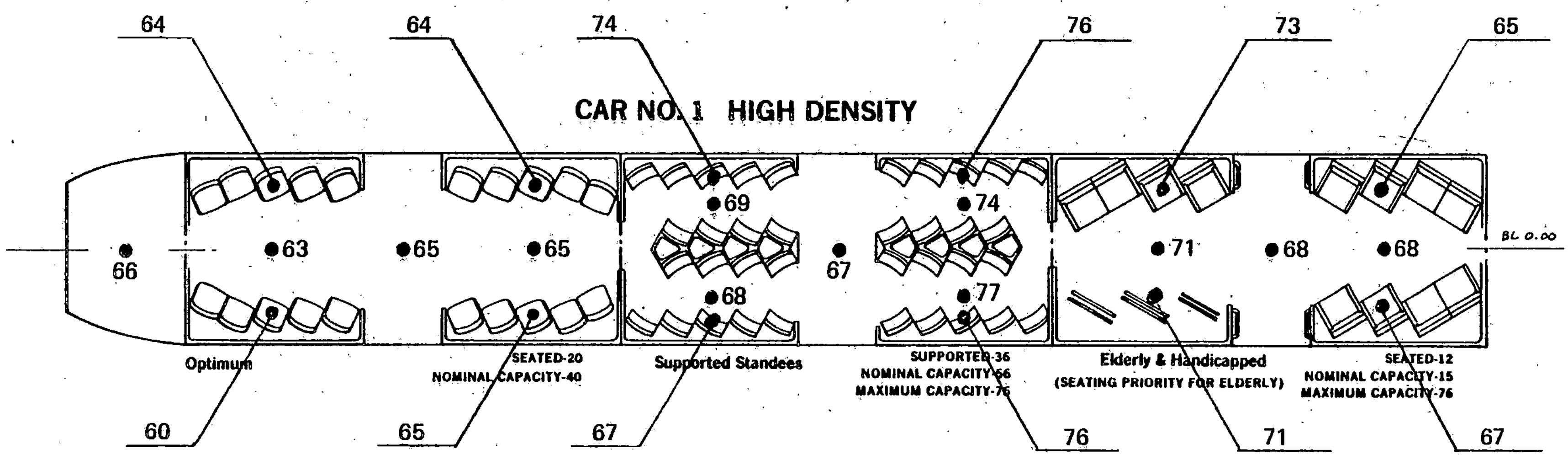

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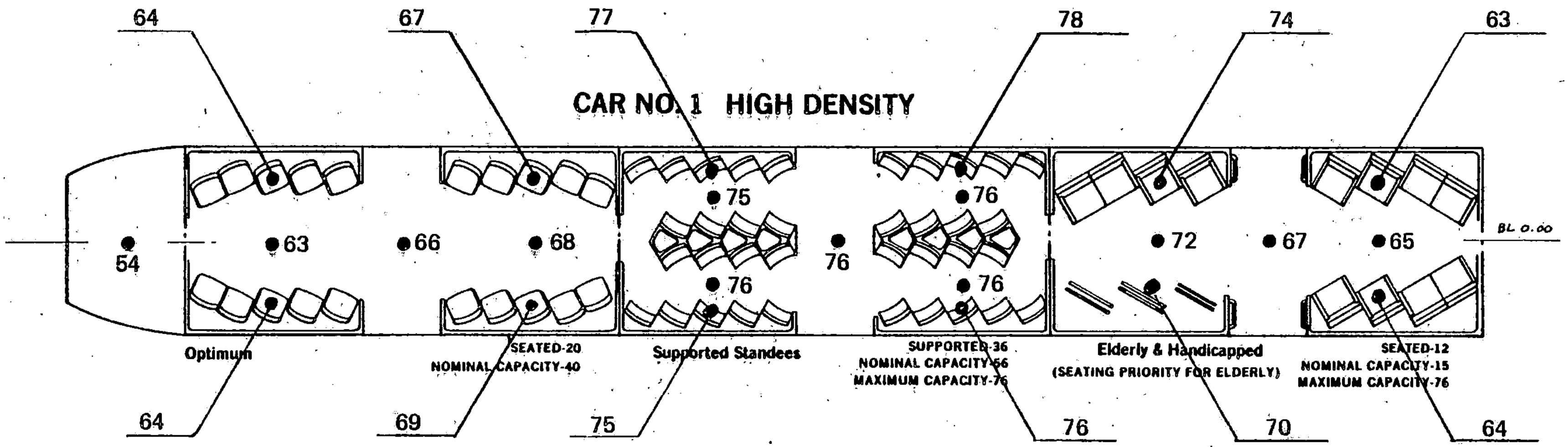


Figure 6–12. Interior Noise Levels With Car Static 88% ESU SPEED
(Sheet 2 of 3)

VENT FAN ON, TURBOCOMPRESSOR ON

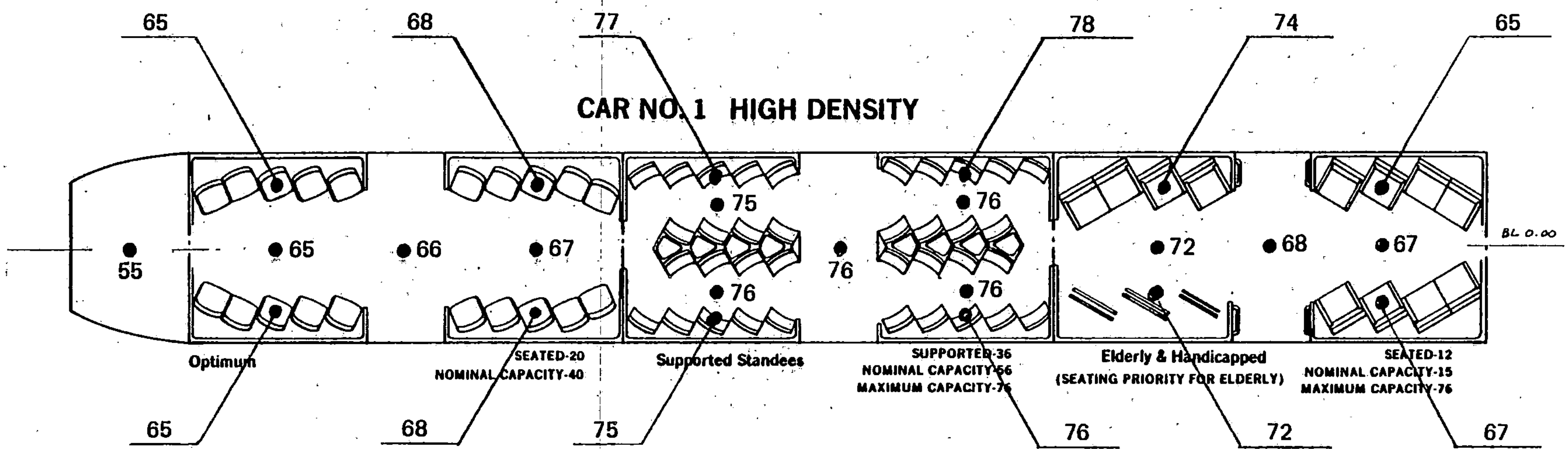
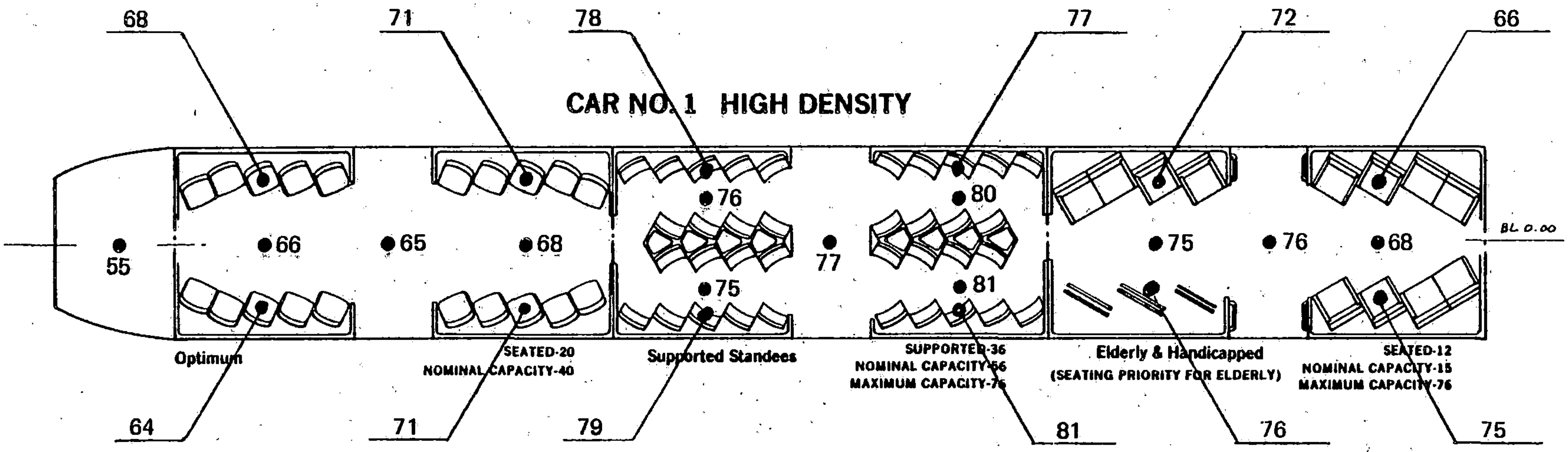


Figure 6–12. Interior Noise Levels With Car Static (Sheet 3 of 3)

88% ESU SPEED

VENT FAN OFF, TURBOCOMPRESSOR OFF



VENT FAN ON, TURBOCOMPRESSOR OFF

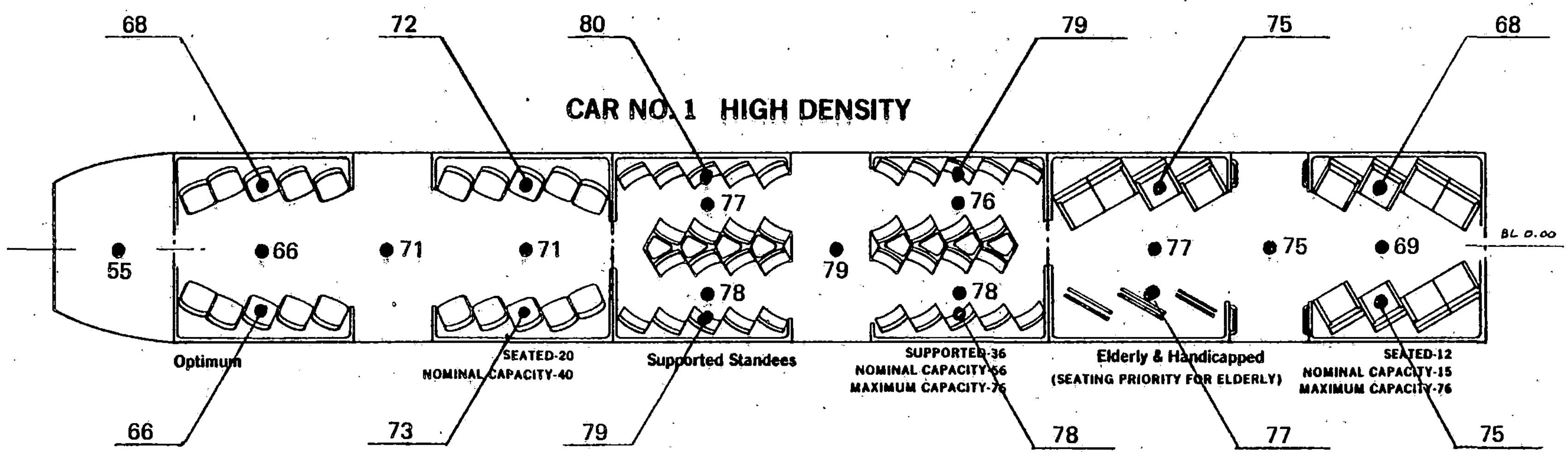


Figure 6–13. Interior Noise Levels With Car Static and ESU at 97.5 Percent
(Sheet 1 of 2)

VENT FAN ON, TURBOCOMPRESSOR ON

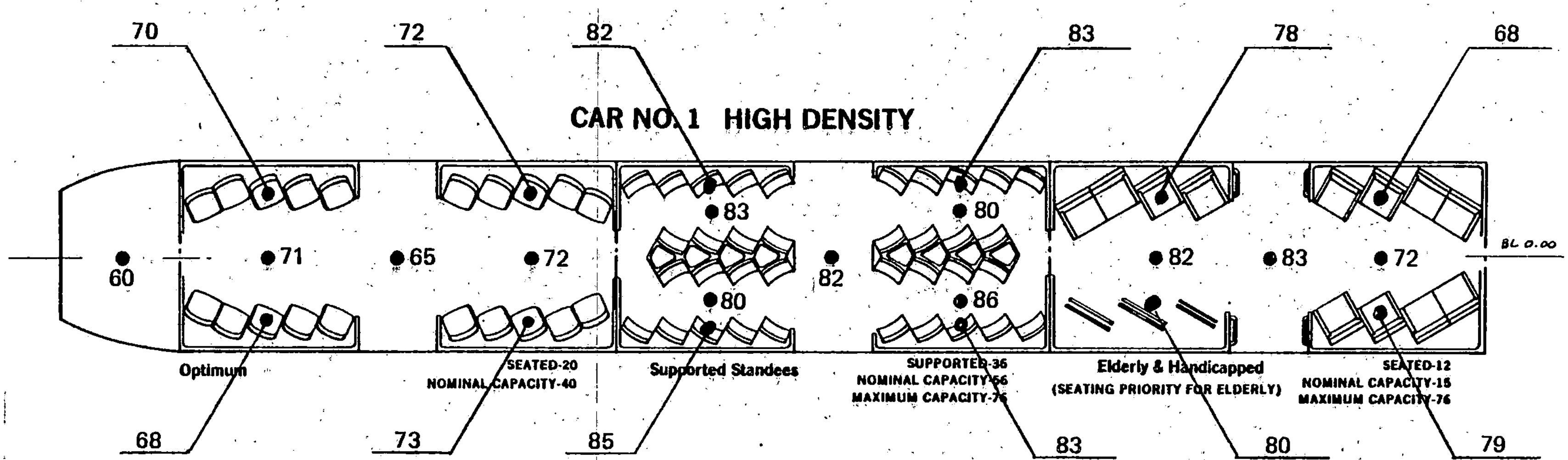


Figure 6–13. Interior Noise Levels With Car Static and ESU at 97.5 Percent
(Sheet 2 of 2)

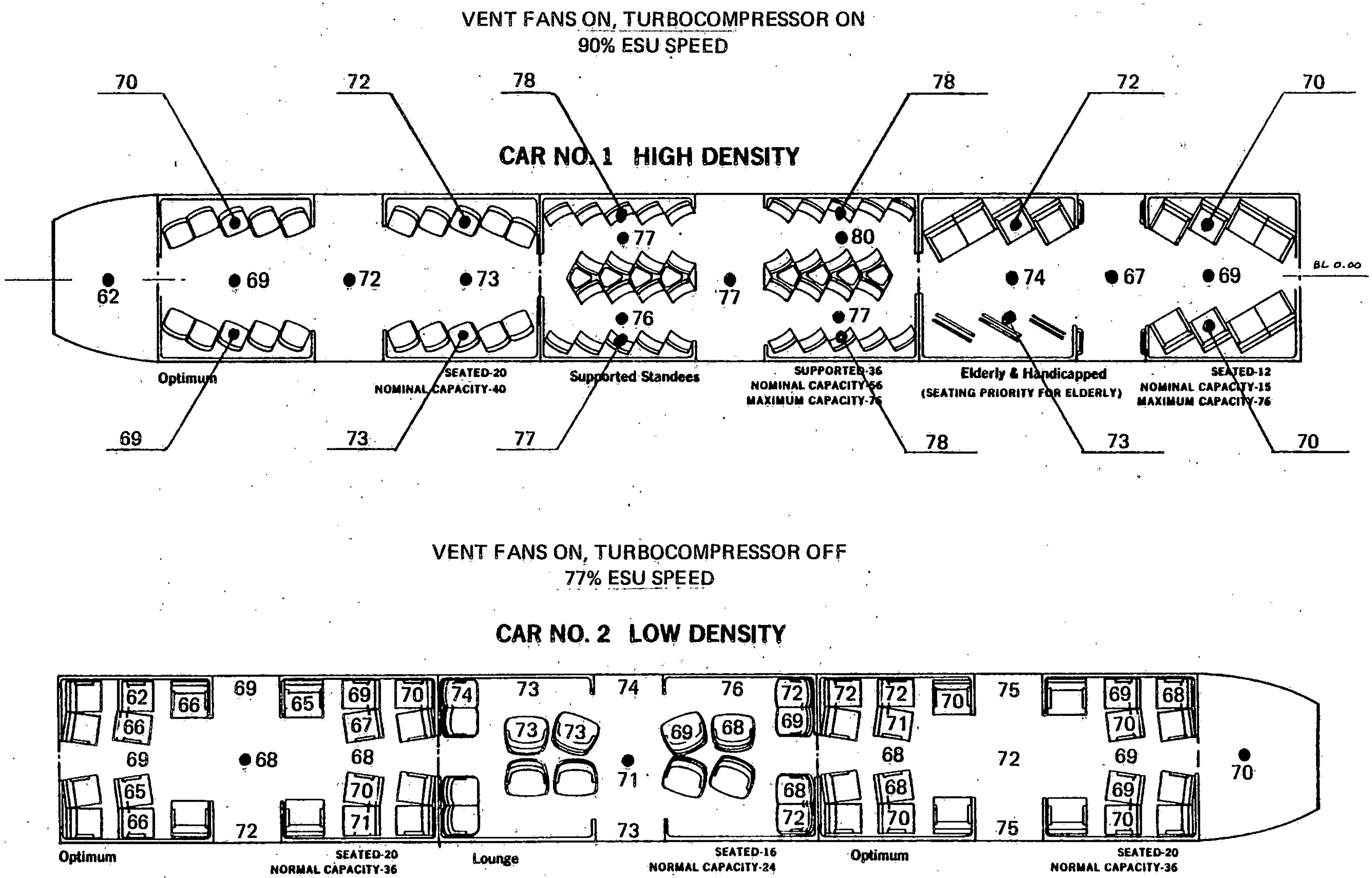


Figure 6–14. Interior Noise Levels at 60 MPH

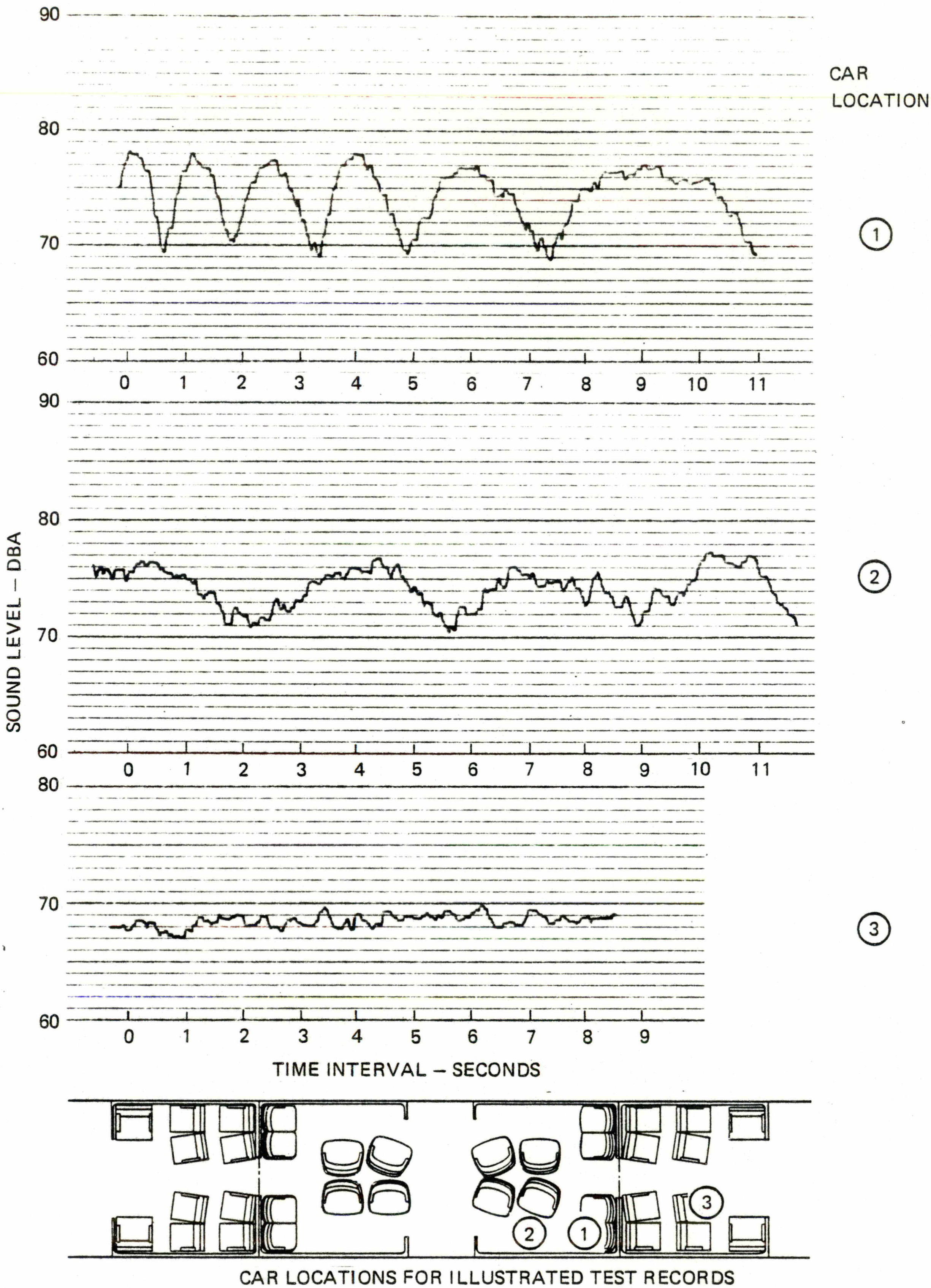


Figure 6–15. Effect of ESU Flywheel Beating on Interior Noise Level of DOTX-4 at 60 MPH

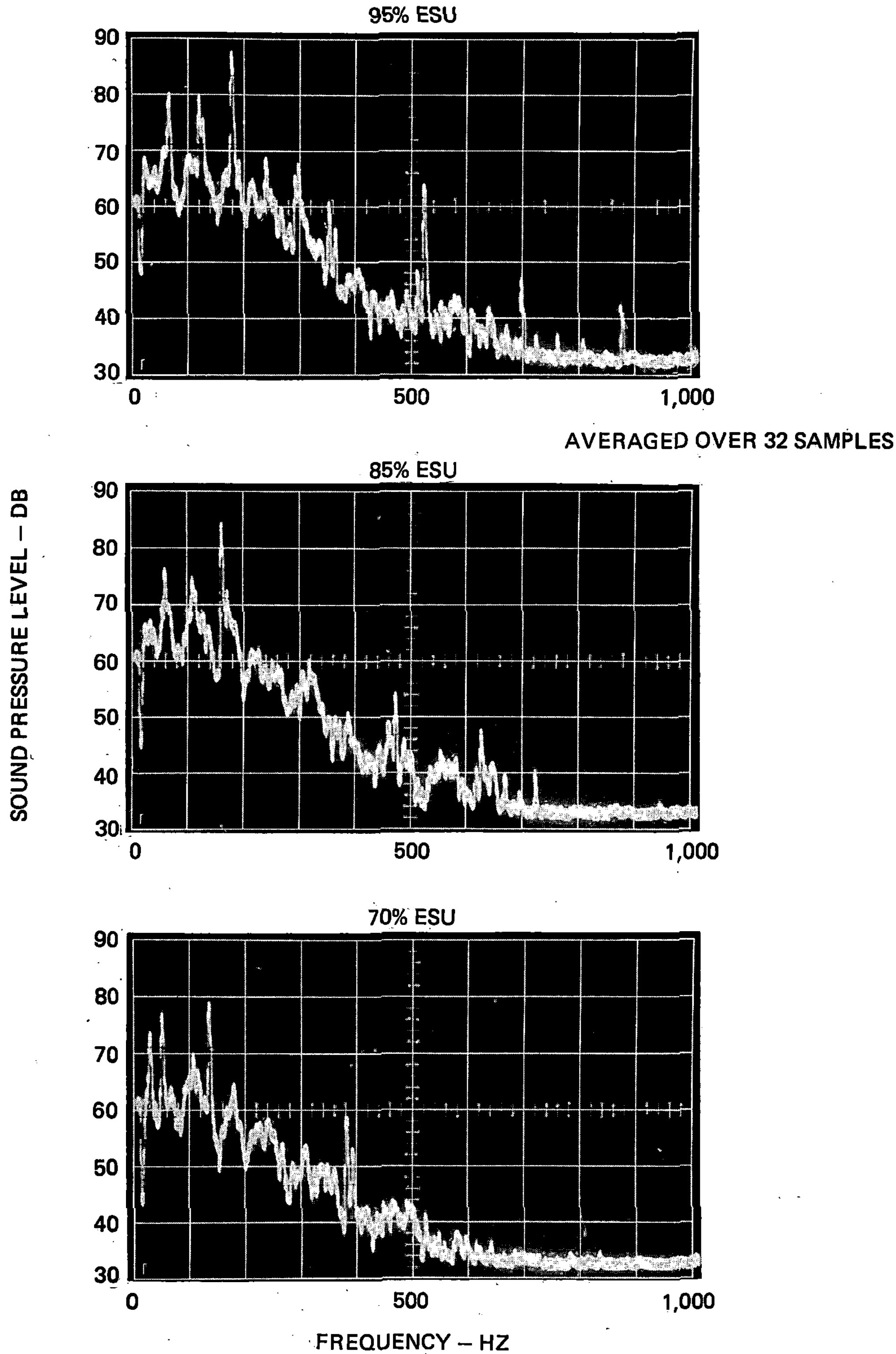


Figure 6–16. Interior Noise Spectra at Center of Car With All Systems Operating

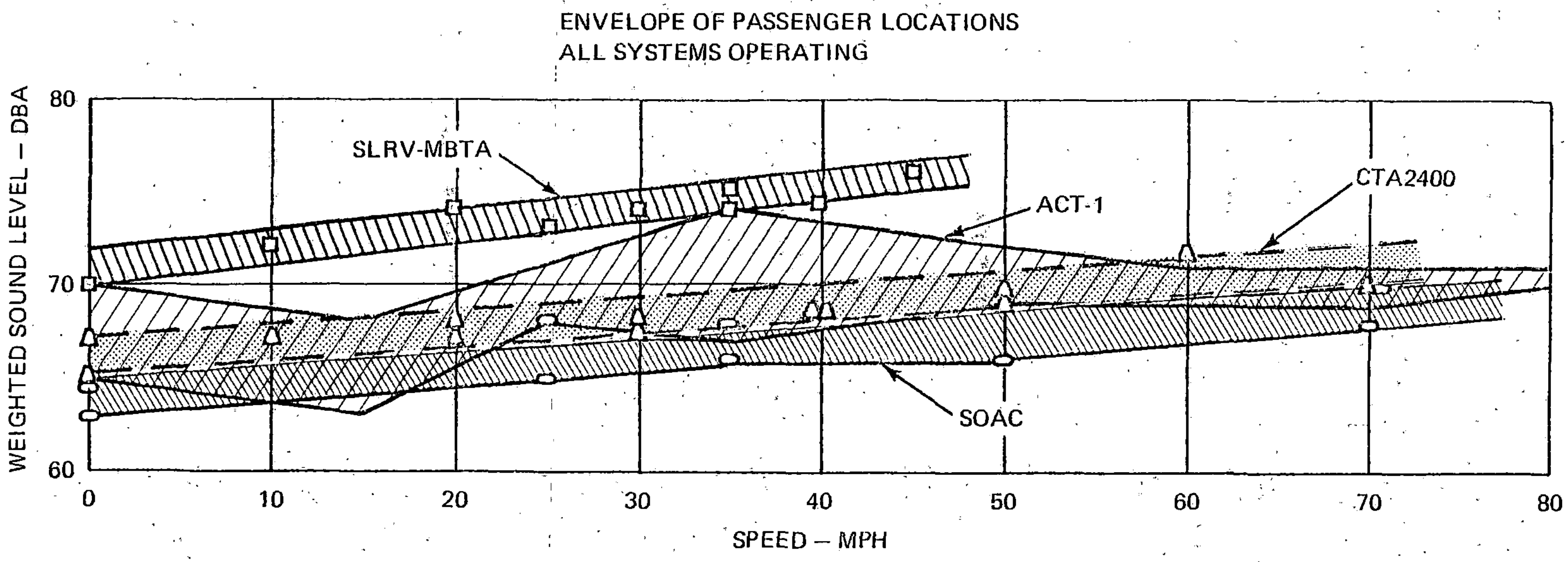


Figure 6–17. Comparison of ACT-1 Interior Noise With Other Transit Vehicles

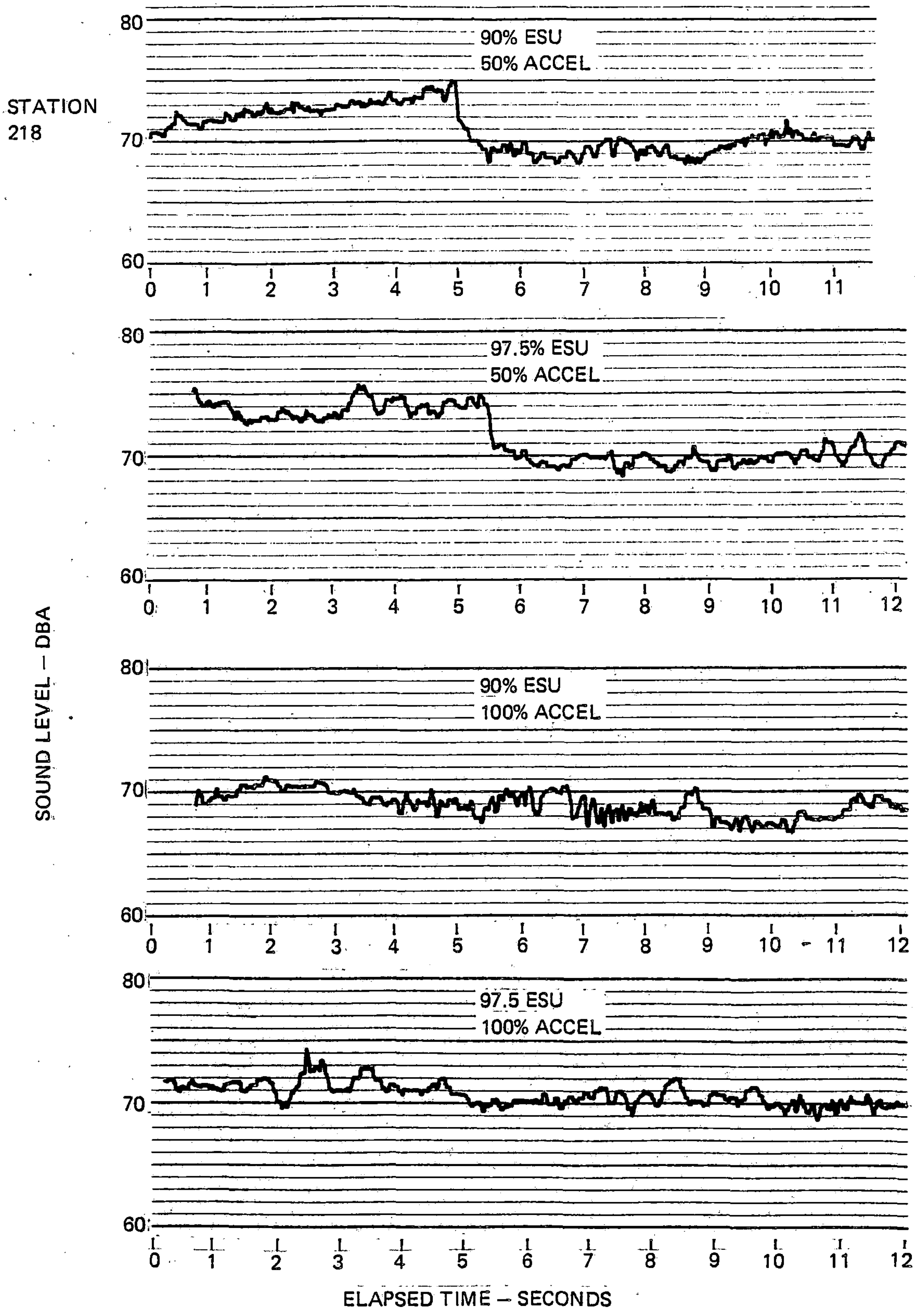
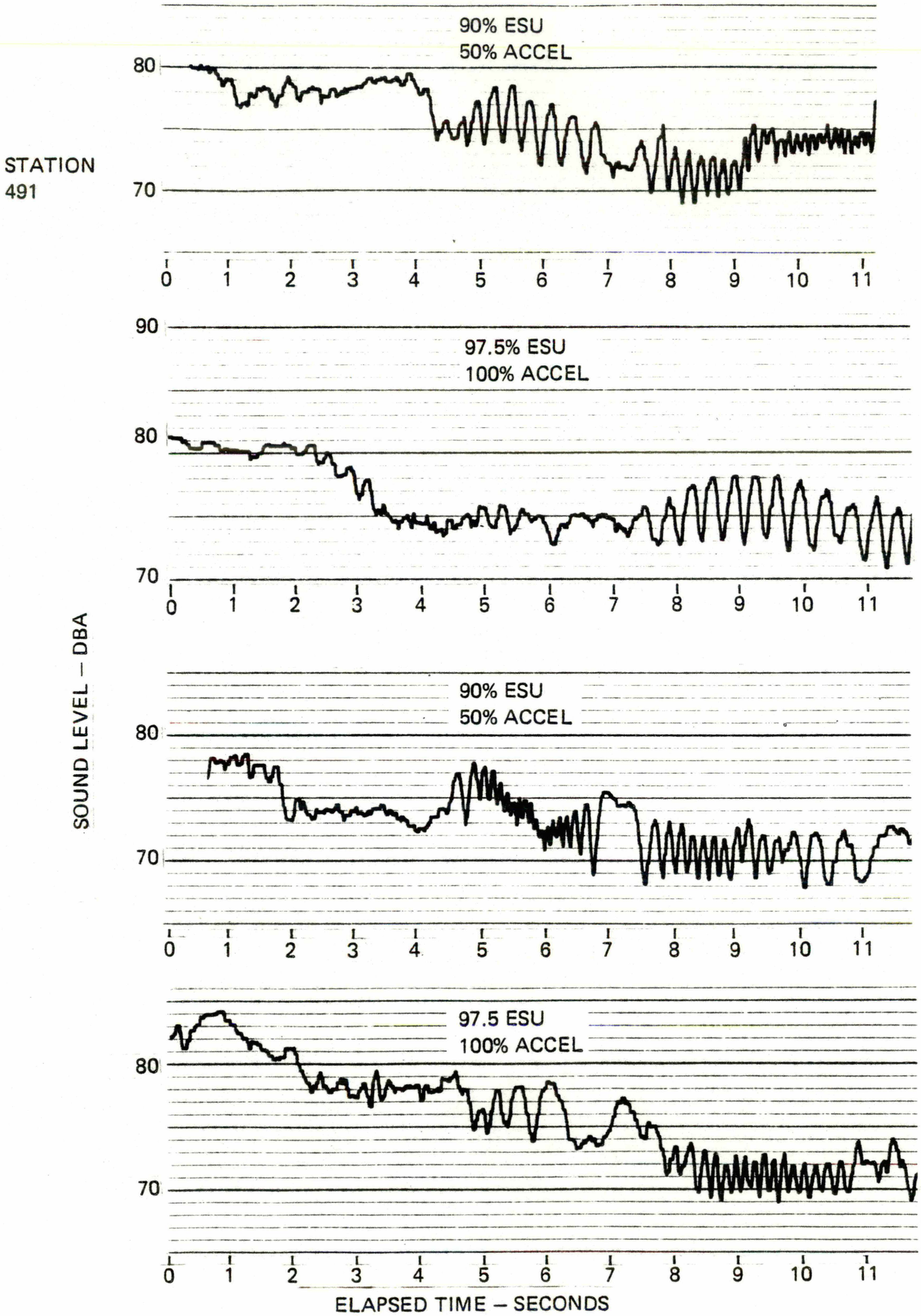


Figure 6–18. Effect of Acceleration on Interior Noise (Sheet 1 of 2)



Sheet 6–18. Effect of Acceleration on Interior Noise (Sheet 2 of 2)

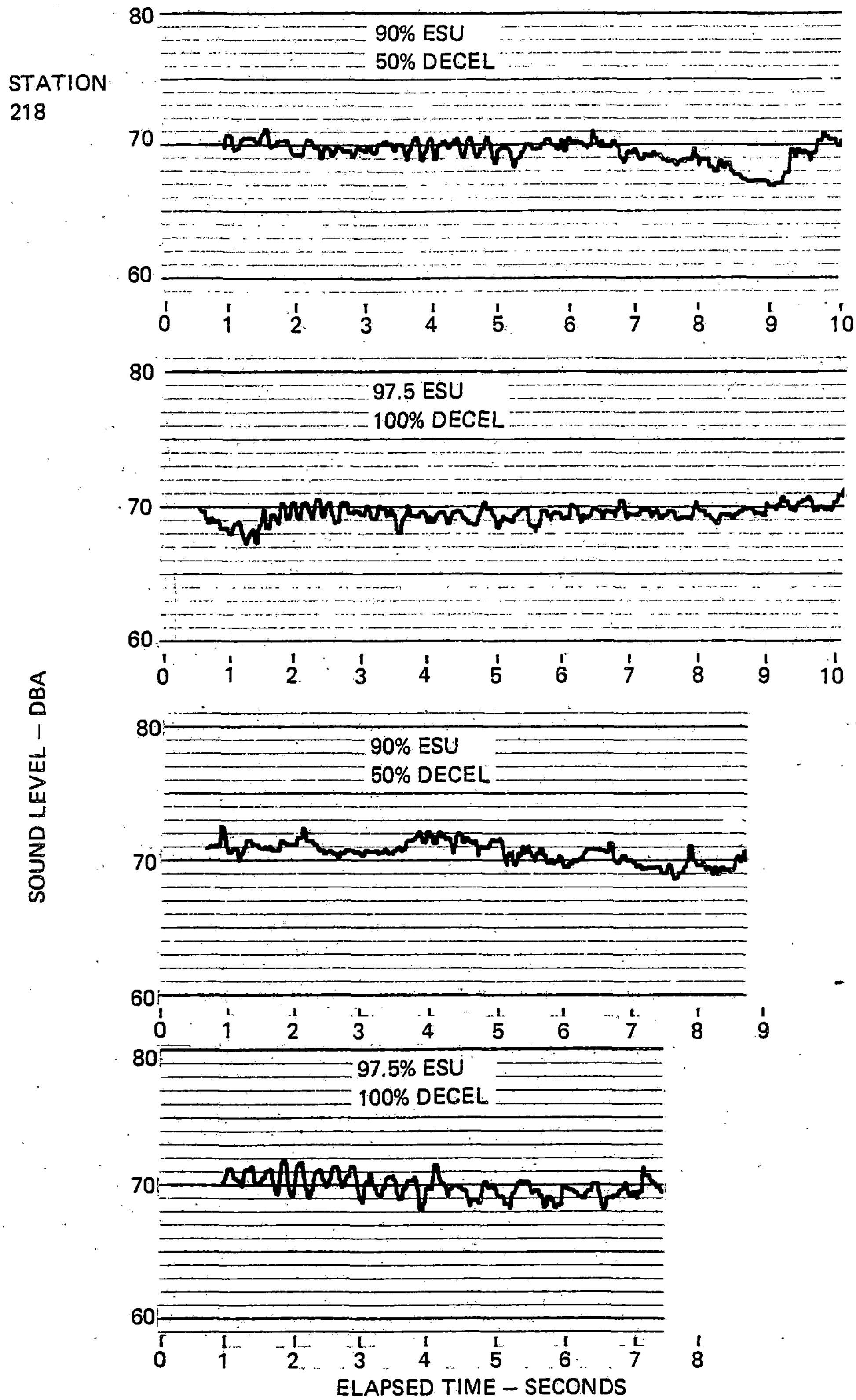


Figure 6–19. Effect of Deceleration on Interior Noise (Sheet 1 of 2)

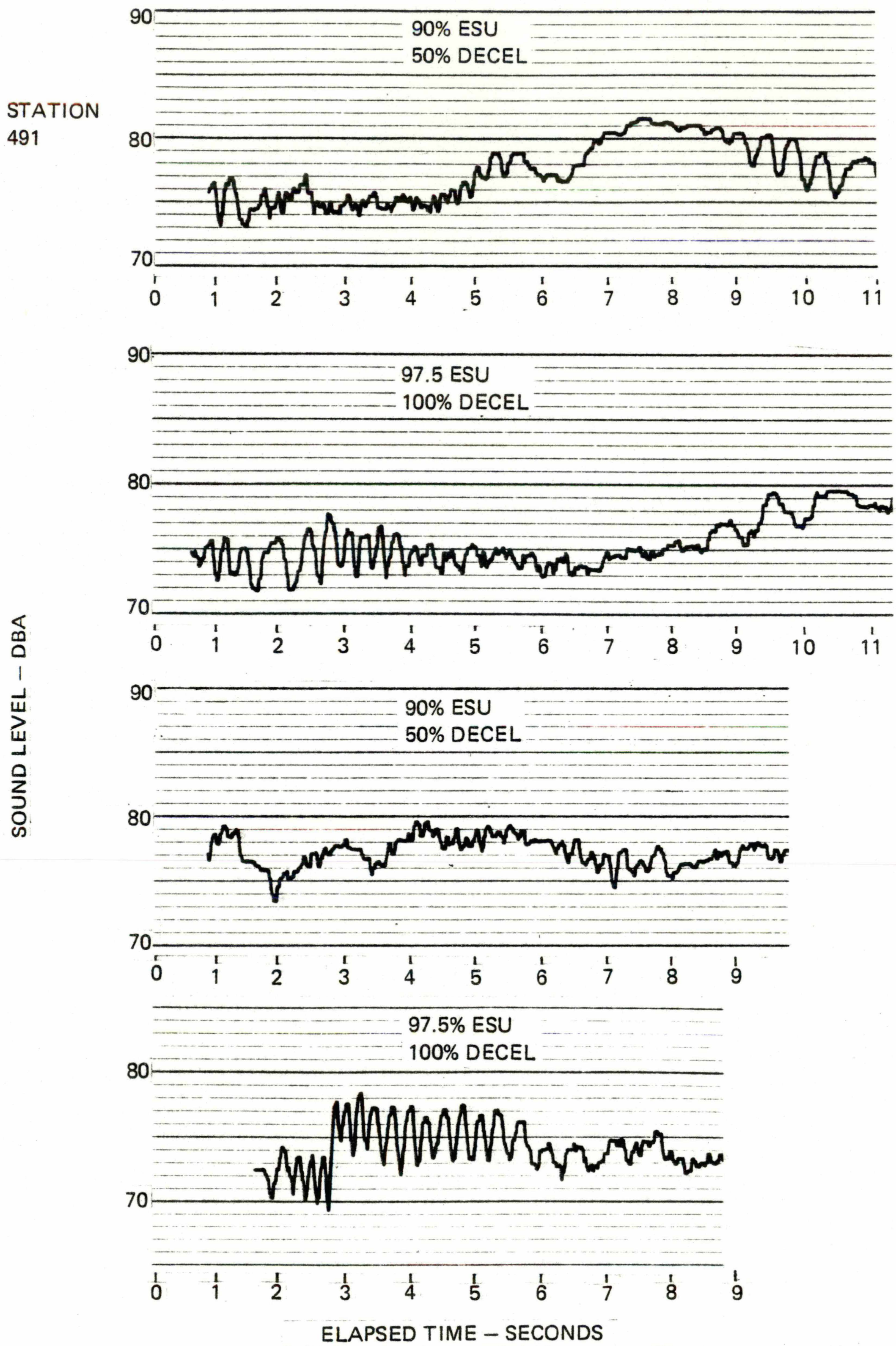


Figure 6–19. Effect of Deceleration on Interior Noise (Sheet 2 of 2)

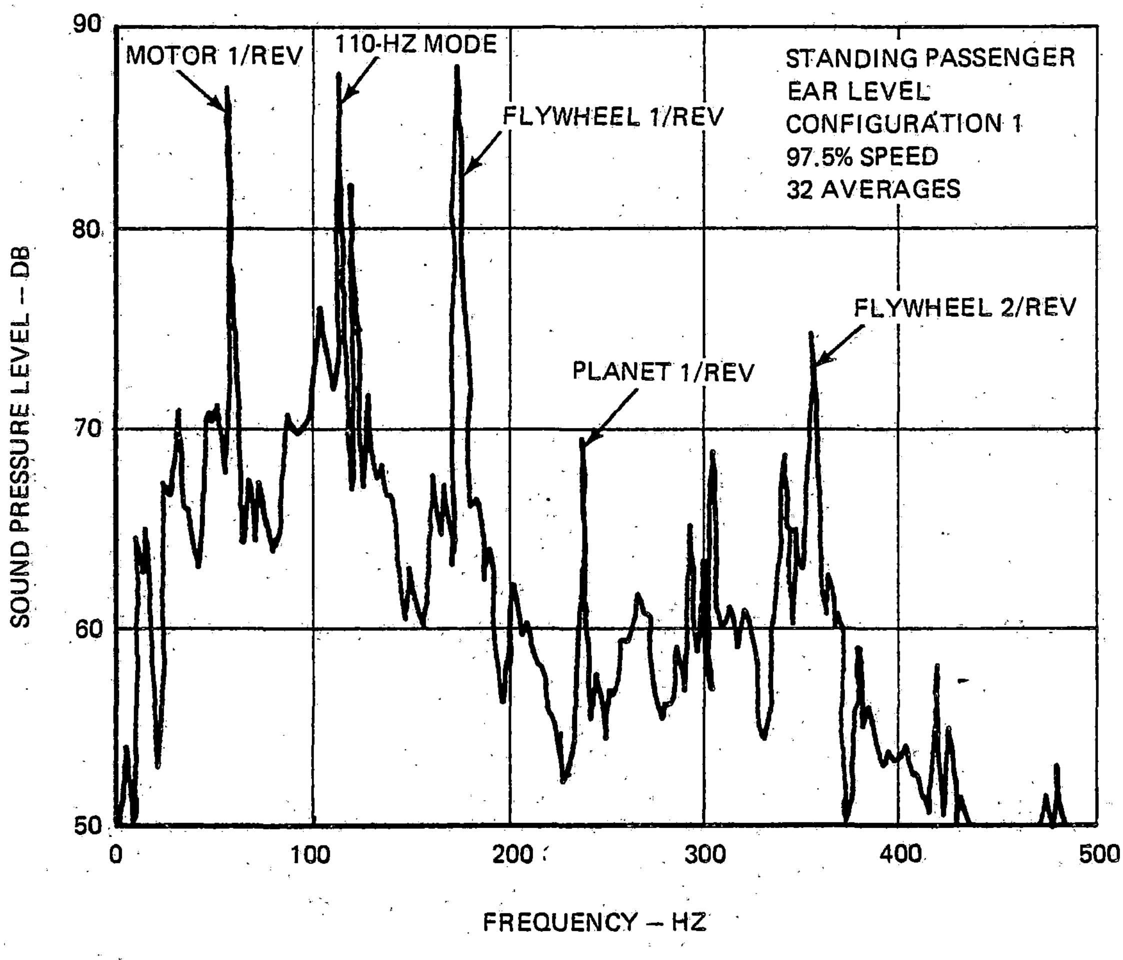


Figure 6–20. Narrowband Analysis of Interior Noise

7.0 MAINTENANCE DEMONSTRATIONS

7.1 INTRODUCTION

In order to evaluate the maintenance concept proposed for the ACT-1 vehicle, several maintenance functions were monitored during the test program at the transportation test center, Pueblo, Colorado.

No specific maintenance demonstrations were conducted; rather, the maintenance functions monitored on each car were those necessary to correct malfunctions occurring to car systems, subsystems, or components.

7.2 DEMONSTRATION TEST CRITERIA

7.2.1 Maintenance Concept

The maintenance functions carried out were performed in accordance with the AiResearch-supplied maintenance manuals and with assistance of on-site AiResearch engineers and technicians.

7.2.2 Maintenance Personnel

The maintenance personnel used to service the ACT-1 vehicle were transportation test center mechanics and technicians, AiResearch engineers and technicians, and Boeing Vertol engineers.

7.2.3 Test Site and Facilities

All the maintenance performed on the ACT-1 vehicles was performed at the transportation test center in the transit maintenance building (TMB) or the central services building (CSB).

7.2.4 Ground Rules

The ground rules for performing the maintenance demonstrations were that all tools were available, there would be no troubleshooting, there were no practice runs to familiarize personnel, and generally, it was an actual maintenance situation. Reacceptance or checkout time after maintenance is not included in demonstration times.

7.3 DEMONSTRATION TEST OBJECTIVES AND RESULTS

Table 7-I shows the maintenance operations that were monitored for record-keeping purposes. The validity of the procedures provided by AiResearch was generally very good.

The actual time required to perform maintenance tasks is shown in Table 7-I.

TABLE 7–I. MAINTENANCE OPERATIONS

Remove and Reinstall	Actual Time Required (manhours)
Side skirts and duct removal; necessary to raise car on jacks	4.5
ESU (includes first item)	41.0
Truck (includes first item)	7.5
Traction motor	40 (with truck removed)
Brake pads	0.5
Brake disc	12 (with truck removed)
Battery	1.0

8.0 ACCEPTANCE TESTS

8.1 SUMMARY

The ACT-1 cars were subjected to a series of acceptance tests in general compliance with Boeing Vertol Company document D174-10039-5, ACT-1 Vehicle On-Track Acceptance Test Procedure.

The acceptance tests were composed of the following major categories.

8.1.1 Performance

The ACT-1 cars were operated in accordance with the key performance parameters defined in the test plan to show compliance with the design requirements. Results of the vehicle acceleration and braking rates, together with the resultant dead time and jerk rates, are presented in the acceptance test documents, D174-10048-1, Advanced Concept Train DOTX-5 Vehicle Acceptance Report, and D174-10048-2, Advanced Concept Train DOTX-4 Vehicle Acceptance Report.

The detailed performance data in this report is integrated with the engineering performance test results in Section 4.0.

8.1.2 Noise Environment

The wayside and carbody interior noise environment was determined for the static condition with systems operating and for acceleration, deceleration, and constant-speed conditions. The test results are summarized in the acceptance test document, D174-10048-1, with more detailed analysis included as Section 6.0 of this report.

Results show that the noise levels exceed the design goal, with the energy storage unit (ESU) being the most significant noise source.

8.1.3 Ride Quality

The vertical and lateral ride quality results summarized in the acceptance test document, D174-10048-1, show that the specification limits have been exceeded. However, a subjective assessment is that the ride quality is acceptable. As a reference point, the ride quality meets the State-of-the-Art Car (SOAC) specification. The SOAC ride quality was judged good by most transit passengers.

The detailed ride quality data is included as Section 5.0 of this report.

8.1.4 Heating, Ventilating, and Air Conditioning (HVAC)

The HVAC tests were conducted in accordance with AiResearch document 77-14307, Revision A, Vehicle Heating, Ventilation, and Air Conditioning System Test Procedure at TTC, Pueblo, Colorado.

Detailed test results, which are presented in Section 3.7 of this document, indicate the heating system is marginally adequate to meet specification requirements. The air-conditioning system is deficient.

APPENDIX A

ACT-1 INSTRUMENTATION

1.0 INSTRUMENTATION

1.1 PERFORMANCE, RIDE QUALITY, AND STRUCTURE TESTS

The purpose of the instrumentation system for the Advanced Concept Train (ACT-1) is to measure and record the operating characteristics of the vehicle. These characteristics have been grouped into three categories, performance, ride quality, and structural behavior. Ride quality denotes those attributes which affect the comfort or well-being of the passengers and includes various components of linear and angular acceleration. Structural behavior includes the stresses in various members of the vehicle and the relative motions of the truck with respect to the vehicle frame. Performance relates to the speed, acceleration, and braking characteristics of the car and the electrical power required to operate the vehicle.

A block diagram of the system is shown in Figure A-1. The ACT-1 system is primarily the SOAC system, report no. UMTA-MA-06-0025-75-6, with an increased number of parameters. The measured parameters include linear and angular accelerations, relative motions, strains, temperatures, voltage, current, electrical power, and wheel speeds (see Table A-I for parameter listing). These quantities are measured by appropriate transducers mounted on various parts of the vehicle. Electrical signals from these transducers are conducted by cables to an interface panel which is connected to an instrumentation console. The console contains two magnetic tape recorders, two light-beam oscillographs, a time-code generator, a temperature recorder, and the signal conditioning required to power the transducers and convert their signals to a level compatible with the magnetic tape recorders. Equipment temperatures are measured by thermocouples and are recorded directly by the temperature recorder. The other transducer cables are connected to their respective signal-conditioning units.

The outputs of the signal-conditioning units can be selectively recorded on the two tape recorders and the oscillographs. Any 28 selected parameters can be recorded on tape. These same parameters can also be recorded on the oscillographs. In addition, signals corresponding to wheel speeds are recorded directly on the oscillographs. Total power consumption is recorded on tape and displayed on a mechanical counter. The time-code generator provides signals that are recorded on tape and on the oscillograph traces for facilitating subsequent analysis of test data.

The test-recording scheme is based on conducting separate tests for ride quality, structural behavior, and overall vehicle performance. Not enough recording channels are provided to record simultaneously all conditioned transducer outputs. The recording system has been designed to achieve flexibility, operational convenience, and trouble-free operation.

An important feature of the system is that all of the signal conditioning and recording equipment can be removed from the vehicle when not needed. The transducers are permanently mounted and are connected electrically to interface panels located in junction boxes mounted beneath the floor. Connection to the signal-conditioning and recording equipment is made by removing cover plates which form part of the floor of the car and connecting cables to the interface panels. When the car is used for demonstration runs, the instrumentation console is disconnected and removed from the car. The cover plates serve to protect and conceal the instrumentation interface panel during demonstration runs on the transit properties.

1.2 NOISE TESTS

1.2.1 Interior Noise

The instrumentation used for measurement of noise levels consists of a 1-inch condenser microphone with battery-operated cathode follower and a 1/4-inch, single-channel tape recorder. For interior measurements, the tape recorder/microphone pair are operated as a portable unit. An accelerometer is used for structureborne noise measurements. The recorder is operated at a tape speed of 7-1/2 ips to achieve a good frequency response characteristic. A gain attenuation system consisting of 10-db incremental steps is incorporated into the recorder to maintain accuracy of the system (Figure A-2).

1.2.2 Exterior (Wayside) Noise

The instrumentation used for measurement of noise levels consists of a 1-inch condenser microphone with battery-operated cathode follower and a 1/4-inch, single-channel tape recorder. For wayside measurements, the microphone is mounted on a tripod for each of the passby measurements and a windscreen installed to reduce the interference of wind on the data. The recorder is operated at a tape speed of 7-1/2 ips to achieve a good frequency response characteristic. A gain/attenuation system consisting of 10-db incremental steps was incorporated in the recorder to maintain accuracy of the system.

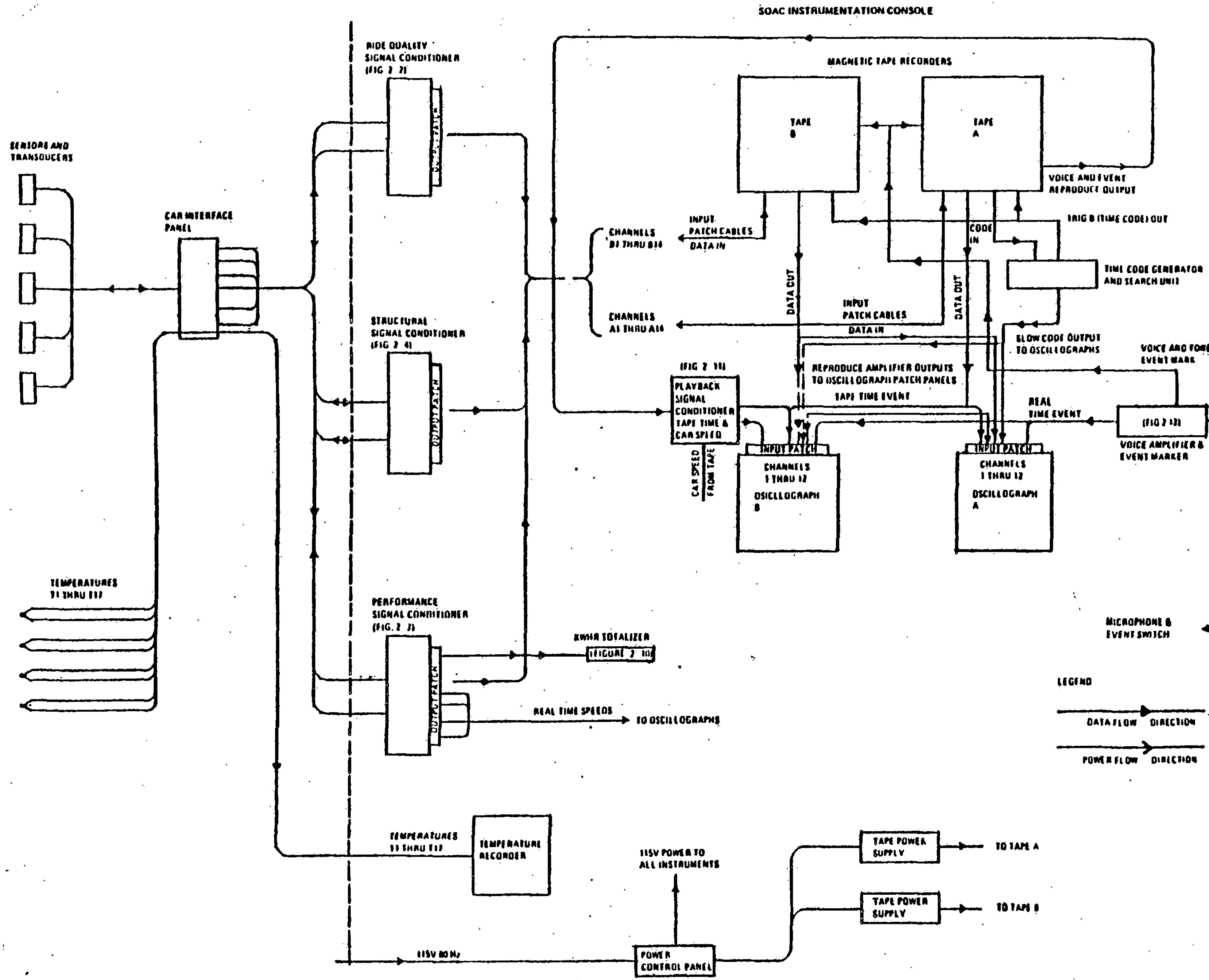


Figure A–1. SOAC Instrumentation System Block Diagram

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TABLE A–I. INSTRUMENT RECORDING DATA

CODE	PARAMETER	TRANSDUCER TYPE	MODEL	RANGE	REQUIRED RANGE	FREQ. RESP.	LIN.	HYST.	REPEAT.	SYSTEM ACCY.	DISPLAY TAPE RECORD	O'GRAPH	VISUAL	OTHER	REMARKS
	VOLTAGE														
101	FWD ESU ALTERNATOR-AC-LINE TO LINE	A/R	LSK 36221	300V	0-300V	0-400 Hz				±2%	X	X			5V pk = 400Vpk
102	AFT ESU ALTERNATOR-AC-LINE TO LINE			300V	0-300V	0-400 HZ				±2%	X	X			5V pk = 400Vpk
103	LOW VOLTAGE POWER SUPPLY			60V	0-60V	0-400Hz				±2%	X	X			5V = 60V
104	FWD ESU ARMATURE			1500V	0-1500V	0-400 Hz				±2%	X	X			5V = 1500V
105	AFT ESU ARMATURE			1500V	0-1500V	0-400Hz				±2%	X	X			5V = 1500V
106	TRACTION MOTOR 'A' ARMATURE			1500V	0-1500V	0-400Hz				±2%	X	X			5V = 1500V
107	TRACTION MOTOR 'B' ARMATURE			1500V	0-1500V	0-400Hz				±2%	X	X			5V = 1500V
108	THIRD RAIL		LSK 36271	1000V	0-800V	0-400Hz				±2%	X	X			5V = 1000V
109	AFT E.P. DYN BRAKE FEEDBACK SIGNAL		ECU	10V	0-10V	0-400Hz				±2%	X	X			5V = 100% @ AW3
110	PROPULSION SYSTEM DRIVE (TRAINLINE)			40V	0-40V	0-30 Hz				±2%	X	X			ON/OFF
111	FWD E.P. DYN BRAKE FEEDBACK SIGNAL	A/R	ECU	10V	0-10V	0-400Hz				±2%	X	X			5V = 100% @ AW3
	POWER														
151	CAR INPUT	A/R			2 MW-HR					±3%	X	X	X		

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CODE	PARAMETER	TRANSDUCER								SYSTEM	DISPLAY				REMARKS
		TYPE	MODEL	RANGE	REQUIRED RANGE	FREQ. RESP.	LIN.	HYST.	REPEAT.	ACCY.	TAPE RECORD	O'GRAPH	VISUAL	OTHER	
	CURRENT														
201	THIRD RAIL	JANCO SHUNT	8406	2000A	0-2000A	0-400Hz				±2%	X	X			± 5V = 2000 A
202	TRACTION MOTOR 'A' ARMATURE	↓	↓	1000A	0-1000A	0-400Hz				±2%	X	X			± 1V = ± 1000 A
203	TRACTION MOTOR 'B' ARMATURE			1000A	0-1000A	0-400Hz				±2%	X	X			± 1V = ± 1000 A
204	TRACTION MOTOR 'A' FIELD			50A	±50A	0-400Hz				±2%	X	X			± 1V = ± 50A
205	TRACTION MOTOR 'B' FIELD			50A	±50A	0-400Hz				±2%	X	X			± 1V = ± 50A
206	FWD ESU ARMATURE			1000A	0-1000A	0-400Hz				±2%	X	X			± 1V = ± 1000 A
207	AFT ESU ARMATURE			1000A	0-1000A	0-400Hz				±2%	X	X			± 1V = ± 1000 A
208	FWD ESU FIELD	↓	↓	50A	±50A	0-400Hz				±2%	X	X			± 1V = ± 50A
209	AFT ESU FIELD	JANCO SHUNT	8406	50A	±50A	0-400Hz				±2%	X	X			± 1V = ± 50A
210	P SIGNAL	N/R		.25A	0-.25A	0-400Hz				±2%	X	X			D.C. ANALOG 5V = 250 MA
211	LOW VOLTAGE POWER SUPPLY	AAC	909MS	500A	0-300A	0-400Hz				±2%	X	X			± 5V = ± 500 A
212	FWD ESU ALTERNATOR-'A' PHASE	JANCO SHUNT	8406	300A	0-300A	0-400 Hz				±2%	X	X			± 1Vpk = ± 300 A pk
213	AFT ESU ALTERNATOR-'A' PHASE	JANCO SHUNT	8406	300A	0-300A	0-400 Hz				±2%	X	X			± 1Vpk = ± 300 A pk
214	TRK A E.P. VALVE CONVERTER	AAC	905B	1A	0-1A	0-200Hz				±2%	X	X			± 5V = 250 MA
215	TRK B E.P. VALVE CONVERTER	AAC	905B	1A	0-1A	0-200Hz				±2%	X	X			± 5V = 250 MA

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TABLE A–I – Continued

CODE	PARAMETER	TRANSDUCER TYPE	MODEL	RANGE	REQUIRED RANGE	FREQ. RESP.	LIN.	HYST.	REPEAT.	SYSTEM ACCY.	DISPLAY TAPE RECORD	O'GRAPH	VISUAL	OTHER	REMARKS
	RPM/SPEED/DISTANCE														
301	CAR SPEED	A/R	9TH WHEEL	100 MPH	0-100MPH	0-12HZ				±0.5 %	X	X			14.66 Hz/MPH
301	CAR DISTANCE		9TH WHEEL	10 MI	0-10 MI					±0.2%/1000 FT	X	X	X		1 PULSE = .1 FT.
303	FWD ESU SPEED		ECU	100%	0-100%	0-12Hz				±1%	X	X			5V = 100%
304	AFT ESU SPEED		ECU	100%	0-100%	0-12Hz				±1%	X	X			5V = 100%
305	TRACTION MOTOR 'A' SPEED		ECU	100 MPH	0-100MPH	0-12Hz				±1%	X	X			5V = 100 MPH
306	TRACTION MOTOR 'B' SPEED	A/R	ECU	100 MPH	0-100MPH	0-12Hz				±1%	X	X			5V = 100 MPH
	TORQUE/LOADS														
401	TRUCK B-ROLL BAR TORQUE (LINK LOAD)	B/V			0-8000 lb						X	X			1V = 10,000 LBS. R_c = 25KΩ = 1.158V = 11,578 LBS.

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TABLE A–I – Continued

CODE	PARAMETER	TRANSDUCER TYPE	MODEL	RANGE	REQUIRED RANGE	FREQ. RESP.	LIN.	HYST.	REPEAT.	SYSTEM ACCY.	DISPLAY TAPE RECORD	O'GRAPH	VISUAL		REMARKS
	PRESSURE														
501	TRUCK A - BRAKE ACTUATOR	TABER	185	200 PSI	0-200 PSI	0-1000 HZ	±.25%	<±.25%	±.1%	±2%	X	X			Rc = 60k = .994 1V = 100 psi
502	TRUCK B - BRAKE ACTUATOR	TABER	185	200 PSI	0-200 PSI	0-1000 HZ	±.25%	<±.25%	±.1%	±2%	X	X			Rc = 60 k = .991 1V = 100 psi
	STRAIN GAGES					MATERIAL	R/I GAGE NO.	GAGE R: ACCY.	GAGE FACTOR ACCY.						
601	RADIUS ROD ARM BRACKET, L.H.	W.T. BEAM	BAP-06-250-SP-120	20,000 MIN/IN		STEEL	4	±.1%	±1%	±5%	X	X			
602	RADIUS ROD ARM BRACKET, R.H.					STEEL	5			±5%	X	X			
603	SWG. MT. END - ABOVE CORE PLUG WELD, L.H					STEEL	18			±5%	X	X			
604	SIDE FRAME ADJACENT TO OLD LATERAL BRACKET R.H					STEEL	19			±5%	X	X			
605	SIDE FRAME ADJACENT TO OLD LATERAL BRACKET L.H.					STEEL	1			±5%	X	X			
606	AXIAL STRAIN RADIUS ROD R.H.					AL	N/A			±5%	X	X			
607	LATERAL STOP BRACKET L.H.					STEEL	17			±5%	X	X			
608	SWG. MT. END - ACROSS CORE PLUG WELD - ABOVE 603					STEEL	N/A			±5%	X	X			
609	SWG. MT. END UNDER STEEL BRACKET					AL	5			±5%	X	X			
610	SWG. MT. END OPPOSITE 609					AL	9			±5%	X	X			
611	SWG. MT. END BOTTOM HALF					AL	6			±5%	X	X			
612	STEEL CASTING, SWG. ARM BRACKET UPPER HALF					STEEL	16			±5%	X	X			
613	STEEL CASTING, SWG. ARM BRACKET UPPER HALF					STEEL	19			±5%	X	X			
616	AXIAL STRAIN RADIUS ROD L.H.	W.T. BEAM	BAP-06-250-SP-120	20,000 MIN/IN		AL	N/A	±.1%	±1%	±5%	X	X			

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TABLE A–I – Continued

CODE	PARAMETER	TRANSDUCER TYPE	MODEL	RANGE	REQUIRED RANGE	FREQ. RESP.	LIN.	HYST.	REPEAT.	SYSTEM ACCY.	DISPLAY TAPE RECORD	O'GRAPH	VISUAL	OTHER	REMARKS
	VIBRATION														
701	Car Body C/L Floor Sta 491-Vert.	SCHVITZ	LSBC	2G	±1G	0-50 Hz				±5%	X	X			±5V = ±2G
702	Car Body C/L Floor Sta 491-Lat.	SCHVITZ	LSBC	2G	±1G	0-50 Hz				±5%	X	X			±5V = ±2G
704	Car Body C/L Floor Sta 491-Roll	STATHAM	AA17	—	±1.5 Rad/Sec²	0-4 Hz				±5%	X	X			RC = 45K Ω = .965V = .965 RAD ±1V = ±1.0 RAD/SEC²
705	Car Body C/L Floor Sta 491-Pitch	STATHAM	AA17	—	±1.5 Rad/Sec²	0-4 Hz				±5%	X	X			RC = 40K Ω = .919V = .919 RAD ±1V = ±1.0 RAD/SEC²
706	Car Body C/L Floor Sta 491-Yaw	STATHAM	AA17	—	±1.5 Rad/Sec²	0-4 Hz				±5%	X	X			RC = 70K Ω = .981V = .981 RAD ±1V = ±1.0 RAD/SEC²
707	Car Body C/L Floor Sta 648-Vert.	SCHVITZ	LSBC	2G	±1G	0-50 Hz				±5%	X	X			±5V = ±2G
708	Car Body C/L Floor Sta 791-Vert.			2G	±1G	0-50 Hz				±5%	X	X			±5V = ±2G
709	Car Body C/L Floor Sta 791-Lat.			2G	±1G	0-50 Hz				±5%	X	X			±5V = ±2G
711	Car Body C/L Floor Sta 100-Vert.			2G	±1G	0-50 Hz				±5%	X	X			±5V = ±2G
712	Car Body C/L Floor Sta 100-Lat.	SCHVITZ	LSBC	2G	±1G	0-50 Hz				±5%	X	X			±5V = ±2G
721	AFT ESU-Fwd Mount Ring-Vert.	SCHVITZ	LSBC	2G	±2G	0-30 Hz				±5%	X	X			±5V = ±2G
722	AFT ESU-Fwd Mount Ring-Lat.	SCHVITZ	LSBC	2G	±2G	0-30 Hz				±5%	X	X			±5V = ±2G
723	AFT ESU-Aft Mount Ring-Vert.	SETRA	117	2.5G	±2G	0-30 Hz				±5%	X	X			±5V = ±2.5G
724	AFT ESU-Aft Mount Ring-Lat.	SETRA	117	2.5G	±2G	0-30 Hz				±5%	X	X			±5V = ±2.5G
725	AFT ESU-Motor -Long.	SCHVITZ	LSBC	2G	±2G	0-30 Hz				±5%	X	X			±5V = ±2G

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TABLE A–I – Continued

CODE	PARAMETER	TRANSDUCER TYPE	MODEL	RANGE	REQUIRED RANGE	FREQ. RESP.	LIN.	HYST.	REPEAT.	SYSTEM ACCY.	DISPLAY TAPE RECORD	O'GRAPH	VISUAL	OTHER	REMARKS
728	TRK B-T/M Mount C/L Fixed End-Vert.	SCHWITZ	LSBC	20G	±20 G	0-100 Hz				±5%	X	X			±5V = ±20G
729	TRK B-T/M Mount L/H Swg End-Vert.			20G	±20 G	0-100 Hz				±5%	X	X			±5V = ±20G
730	TRK B-T/M Mount R/H Swg End-Vert.			20G	±20 G	0-100 Hz				±5%	X	X			±5V = ±20G
731	TRK B-Axle HSG Primary L/H-Vert.			50G	±25 G	0-500 Hz				±5%	X	X			200 G Spikes ±5V = ±50G
732	TRK B-Axle HSG Primary L/H-Lat.			50G	±25 G	0-500 Hz				±5%	X	X			100 G Spikes ±5V = ±50G
733	TRK B-Axle HSG Primary R/H-Vert.			50G	±25 G	0-500 Hz				±5%	X	X			200 G Spikes ±5V = ±50G
734	TRK B-Frame Pedestal L/H-Vert.			20G	±20 G	0-100 Hz				±5%	X	X			±5V = ±20G
735	TRK B-Frame Pedestal L/H-Lat.			20G	±20 G	0-100 Hz				±5%	X	X			±5V = ±20G
736	TRK B-Diff HSG C/L-Vert.			50G	±25 G	0-500 Hz				±5%	X	X			200 G Spikes (Nose Piece) ±5V=±50G
737	TRK B-Transom C/L T/M Swg MT-Vert.	SCHWITZ	LSBC	20G	±20 G	0-100 Hz				±5%	X	X			±5V = ±20G
738	TRK B-T/M C/L -Vert.	SETRA	117	50G	±20 G	0-100 Hz				±5%	X	X			±5V = ±50G
739	TRK B-T/M C/L -Lat.	SCHWITZ	LSBC	20G	±20 G	0-100 Hz				±5%	X	X			±5V = ±20G
	ACCELERATION														
741	Car Body C/L Floor Sta 491-Long.	SCHWITZ	LSD	.25G	±.25 G	0-16 Hz				±.5%	X	X			±5V = ±.25G

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CODE	PARAMETER	TRANSDUCER TYPE	MODEL	RANGE	REQUIRED RANGE	FREQ. RESP.	LIN.	HYST.	REPEAT.	SYSTEM ACCY.	DISPLAY TAPE RECORD	O'GRAPH	VISUAL	OTHER	REMARKS
	DISPLACEMENT														
801	TRK B-L/H AIRSPRING-VERT.	R/I	4046	3.5 IN	±1.75 IN					±5%	X	X			±5V = ±1.75 IN
802	TRK B-R/H AIRSPRING-VERT.			3.5 IN	±1.75 IN					±5%	X	X			±5V = ±1.75 IN
803	TRK B-R/H AIRSPRING-LAT.			3.5 IN	±1.75 IN					±5%	X	X			±5V = ±1.75 IN
804	TRK B-FWD FRAME TO AXLE L/H-VERT.			.5 IN	±.25 IN.					±5%	X	X			±5V = ±.25 IN
805	TRK B-FWD FRAME TO AXLE R/H-VERT			.5 IN	±.25 IN.					±5%	X	X			±5V = ±.25 IN
806	TRK B-FWD FRAME TO AXLE R/H-LAT.	R/I	4046	.5 IN	±.25 IN.					±5%	X	X			±5V = ±.25 IN
808	TRK A-L/H AIRSPRING - VERT.	R/I	4046	3.5 IN	±1.75 IN					±5%	X	X			±5V = ±1.75 IN
809	TRK A-R/H AIRSPRING - VERT.	R/I	4046	3.5 IN	±1.75 IN					±5%	X	X			±5V = ±1.75 IN

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TABLE A–I – Continued

CODE	PARAMETER	TRANSDUCER TYPE	MODEL	RANGE	REQUIRED RANGE	FREQ. RESP.	LIN.	HYST.	REPEAT.	SYSTEM ACCY.	DISPLAY TAPE RECORD	O'GRAPH	VISUAL	OTHER	REMARKS
	TEMPERATURE														L & N TEMP RECORDER MODEL H, 0-750°F
501	FWD ESU, FWD BEARING	TC	CHROMEL ALUMEL	0-750°F	AMB/500°F					±1%				X	
502	FWD ESU, AFT BEARING				AMB/500°F					±1%				X	
503	FWD ESU OIL				AMB/300°F					±1%				X	
504	AFT ESU, FWD BEARING				AMB/500°F					±1%				X	
505	AFT ESU, AFT BEARING				AMB/500°F					±1%				X	
506	AFT ESU OIL				AMB/300°F					±1%				X	
507	AFT ESU COOLING AIR OUT				AMB/200°F					±1%				X	
508	TRK B-T/M FIELD WINDING				AMB/400°F					±1%				X	
509	TRK B-T/M COMP WINDING				AMB/400°F					±1%				X	
510	TRK B-T/M COOLING AIR OUT				AMB/200°F					±1%				X	
511	TRK B-NO. 4 AXLE G/B OIL SUMP				AMB/350°F					±1%				X	
512	TRK B-NO. 4 AXLE BRAKE DISC				AMB/750°F					±1%				X	
513	INPUT INDUCTOR OUTER COIL (7B)				AMB/200°F					±1%				X	
514	INPUT INDUCTOR INNER COIL (7B)				AMB/200°F					±1%				X	
515	INPUT INDUCTOR COOLING AIR OUT (7B)				AMB/200°F					±1%				X	
516	AIR COMPRESSOR (11B)				AMB/300°F					±1%				X	
517	AIR COMPRESSOR (11B)	TC	CHROMEL ALUMEL	0-750°F	AMB/200°F					±1%				X	

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TABLE A–I – Continued

CODE	PARAMETER	TRANSDUCER TYPE	MODEL	RANGE	REQUIRED RANGE	FREQ. RESP.	LIN.	HYST.	REPEAT.	SYSTEM ACCY.	DISPLAY TAPE RECORD	O'GRAPH	VISUAL	OTHER	REMARKS
918	RECTIFIER HEAT SINK PANAGRAPH (3B)	TC	CHROMEL ALUMEL	0–750°F	AMB/ 200°F					±1%				X	
919	RECTIFIER HEAT SINK 3RD RAIL (3B)				AMB/ 200°F					±1%				X	
920	HVAC-TURB OUT (8B)				35°F					±1%				X	
921	HVAC-COMP MUFFLER OUT (8B)				AMB/ 200°F					±1%				X	
922	HVAC-TURB OUT (6B)				35°F					±1%				X	
923	RESISTOR BANK AIR OUT (4A)*				AMB/ 400°F					±1%				X	
924	COOLING AIR BLOWER OUT PLENUM (10A)				AMB/ 200°F					±1%				X	
925	RECT-FUSE ASSY AIR OUT (11A)				AMB/ 200°F					±1%				X	
926	SENSOR SWITCH ASSY AIR (9A)				AMB/ 200°F					±1%				X	
927	PWR/AC DIST ASSY AIR (8A)				AMB/ 200°F					±1%				X	
928	CONTROL RELAY ASSY AIR (7A)				AMB/ 200°F					±1%				X	
929	LVPS HEAT SINK (13A)				AMB/ 300°F					±1%				X	
930	AFT ESU- FIELD WINDING				AMB/ 400°F					±1%				X	
931	AFT ESU- COMP WINDING	TC	CHROMEL ALUMEL	0–750°F	AMB/ 400°F					±1%				X	

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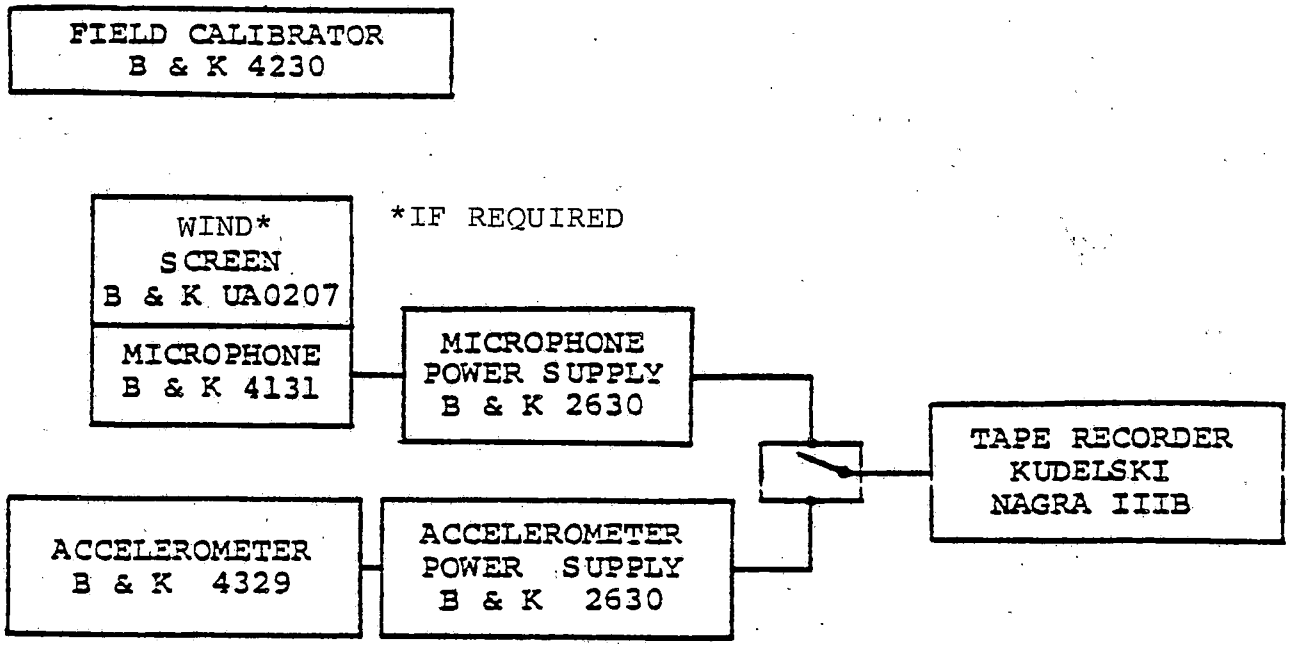
DATA ACQUISITION SYSTEM



DATA REDUCTION SYSTEM

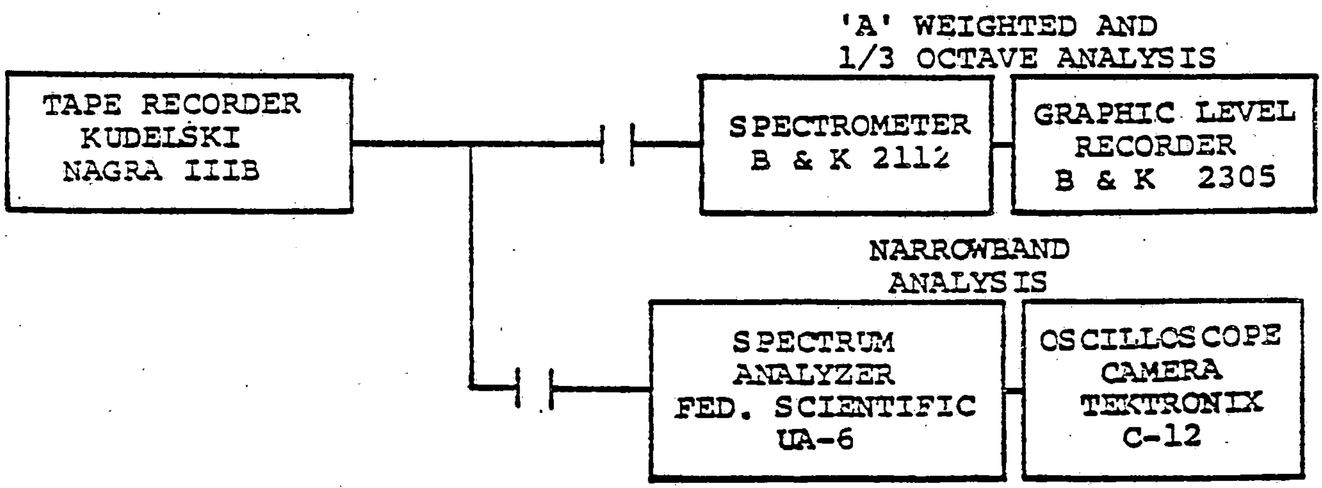


FIGURE A–2. Block Diagrams for Noise Measurement Data Acquisition and Reduction Systems

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